ROYAL ONTARIO NICKEL COMMISSION

Report

OF THE

Royal Ontario Nickel Commission

WITH APPENDIX

PRINTED BY ORDER OF
THE LEGISLATIVE ASSEMBLY OF ONTARIO

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CANADA
PROVINCE OF ONTARIO

GEORGE THE FIFTH by the Grace of God of the United Kingdom of Great Britain and Ireland and of the British Dominions beyond the Seas, King, Defender of the Faith, Emperor of India.

To GEORGE THOMAS HOLLOWAY, of the City of London, England, Associate of the Royal College of Science, London, Vice-President of the Institution of Mining and Metallurgy:

WILLET GREEN MILLER, M.A., LL.D., of the City of Toronto, in the County of York, and Province of Ontario, Provincial Geologist:

McGREGOR YOUNG, M.A., of the City of Toronto, one of His Majesty's Counsel, and

THOMAS WILLIAM GIBSON, of the said City of Toronto, Deputy Minister of Mines:

GREETING:

WHEREAS in and by an Act of the Legislative Assembly entitled "An Act respecting Inquiries concerning Public Matters" it is enacted that whenever the Lieutenant-Governor in Council deems it expedient to cause inquiry to be made concerning any matter connected with or affecting the good government of Ontario, or the conduct of any part of the public business thereof, or the administration of justice therein, and such inquiry is not regulated by any special law, he may, by Commission, appoint a person or persons to conduct such inquiry and may confer the power of summoning any person and requiring him to give evidence on oath, and to produce such documents and things as the Commissioner or Commissioners may deem requisite for the full investigation of the matters into which they are appointed to examine, and the Commissioner or Commissioners shall have the same power to enforce the attendance of witnesses and to compel them to give evidence and to produce documents and things as is vested in any Courts in Civil Cases:

AND WHEREAS Our Lieutenant-Governor in Council of Our said Province of Ontario deems it expedient that full inquiry shall be made into and report made upon the resources, industries and capacities both present and future of this Our Province in connection with Nickel and its Ores, and at the same time, into and upon a just and equitable system of taxation by Our said Province of the mines, minerals and mineral industries thereof, and generally into and upon all such other matters or things as you may think relevant or germane to any of such inquiries, and that the powers authorized by the said Act be conferred upon You:

NOW KNOW YE that we having and reposing full trust and confidence in you the said George Thomas Holloway, Willet Green Miller and McGregor Young, DO HEREBY by and with the advice of Our Executive Council of Our said Province APPOINT you the said George Thomas Holloway, Willet Green Miller and McGregor Young to be OUR COMMISSIONERS in this behalf with the powers authorized by the said Act to inquire into and investigate and report to Our said Lieutenant-Governor upon the matters and things hereinbefore mentioned, and for greater certainty but without restricting the generality thereof upon the following, that is to say:

(*a*) The modes of occurrence, deposits, supply, mining, products, by-products and alloys of nickel in Our said Province and elsewhere, together with the present probable and possible uses thereof and of such products, by-products and alloys:

(b) The smelting, refining, manufacture and treatment of nickel, its ores, products, by-products and alloys within Our said Province and elsewhere, with special reference to treatment, refinement, employment and uses thereof within the said Province:

(c) The demand and market for nickel, its ores and products, by-products and alloys:

(d) Nickel and allied industries with their probable development and requirements, and with special reference to their extension and development within Our said Province:

(e) Such matters as in your opinion will assist Our Lieutenant-Governor in Council to provide a system of taxation upon mines, mining lands, claims or rights, minerals and industries connected with mining that will be just and equitable and in the best interests of Our said Province:

(f) Such further and other matters as in your opinion may relate to or have any bearing upon any of the foregoing subjects of inquiry, having regard to the best interests of this Our Province and of Our Dominion of Canada and of Our Empire:

AND WE DO HEREBY APPOINT YOU the said George Thomas Holloway to be the Chairman, and you, the said Thomas William Gibson to be the Secretary of this Our Commission, which shall be called and known as "The Ontario Nickel Commission."

AND WE DO HEREBY GIVE UNTO and confer upon you, Our said Commissioners, the power of summoning any person and requiring him to give evidence on oath and to produce to you Our said Commissioners such documents and things as you may deem requisite for the full investigation of the premises, together with all and every other power and authority in the said Act mentioned and authorized to be by us conferred on any Commissioner appointed by authority or in pursuance thereof:

AND WE DO HEREBY GIVE UNTO and confer upon you, Our Commissioners, full power to procure such assays and analyses, make such tests, demonstrations and experiments and to make all such engagements and contracts and secure expert or other assistance for any such purposes as you may require, provided that no charges or expenses for any particular service exceeding Five Hundred Dollars shall be incurred without the written approval of Our Minister of Lands, Forests and Mines for Our said Province, and with such approval to erect, equip, maintain and operate such plants, laboratories, works, buildings, machinery or appliances within Our said Province as in your opinion may be required for or in connection with any of the foregoing inquiries:

WE HEREBY ORDAIN AND DECLARE that the fees and expenses of you Our said Commissioners and of you Our Secretary and the reasonable and necessary witness fees and conduct money of witnesses giving evidence before you Our said Commissioners according to the tariff of fees of the Supreme Court of Ontario and the fees and expenses according to the recognized government tariff of the Court Stenographer or any stenographer or stenographers required by you, together with any fees, costs, charges, payments or expenses incurred and certified by you Our Commissioners under any powers or authorities hereinbefore conferred upon you be paid by Our Province of Ontario:

AND WE DO REQUIRE you our said Commissioners forthwith after conclusion and completion of your inquiries to make full report to Our said Lieutenant-Governor touching the said investigation, together with all or any evidence taken by you in connection with or concerning the same, or any further or other material you may consider advisable:

AND WE DO FURTHER ORDAIN AND DECLARE that you the said Commissioners and you the said Secretary shall have, hold and enjoy your said offices and authorities for and during the pleasure of Our said Lieutenant-Governor in Council:

IN TESTIMONY WHEREOF We have caused these OUR LETTERS to be made PATENT and the GREAT SEAL OF OUR PROVINCE OF ONTARIO to be hereunto affixed:

WITNESS:—HIS HONOUR SIR JOHN STRATHEARN HENDRIE, Knight Commander of Our Most Distinguished Order of St. Michael and St. George, Commander of Our Royal Victorian Order, a Lieutenant-Colonel in Our Militia of Canada, etc., etc., etc., LIEUTENANT-GOVERNOR OF OUR PROVINCE OF ONTARIO, AT OUR GOVERNMENT HOUSE, in Our City of Toronto, in Our said Province, this ninth day of September in the year of Our Lord one thousand nine hundred and fifteen and in the sixth year of Our Reign.

BY COMMAND:

F. V. JOHNS,
Acting Assistant Provincial Secretary.

SUPPLEMENTARY COMMISSION

I. R. LUCAS,
Attorney-General.

G.S.

JOHN S. HENDRIE.

CANADA
PROVINCE OF ONTARIO

GEORGE THE FIFTH by the Grace of God of the United Kingdom of Great Britain and Ireland and of the British Dominions beyond the Seas, KING, Defender of the Faith, Emperor of India.

TO GEORGE THOMAS HOLLOWAY, of the City of London, England, Associate of the Royal College of Science of the City of London, Vice-President of the Institution of Mining and Metallurgy; WILLET GREEN MILLER, M.A., LL.D., of the City of Toronto, in the County of York, and Province of Ontario, Provincial Geologist; McGREGOR YOUNG, M.A., of the said City of Toronto, One of Our Counsel; and THOMAS WILLIAM GIBSON, of the said City of Toronto, Esquire, Deputy Minister of Mines;

GREETING:

WHEREAS pursuant to the provisions of an Act of the Legislative Assembly of the Province of Ontario entitled "An Act respecting Inquiries Concerning Public Matters" a Commission was issued under the Great Seal of Our Province of Ontario, dated the ninth day of September, 1915, whereby you the said GEORGE THOMAS HOLLOWAY, WILLET GREEN MILLER, McGREGOR YOUNG and THOMAS WILLIAM GIBSON were appointed a Commission to be called and known as The Ontario Nickel Commission;

AND WHEREAS it is deemed advisable that the said Commission shall be called and known as "Royal Ontario Nickel Commission";

NOW KNOW YE that with the advice of Our Executive Council of Our said Province WE DO HEREBY DIRECT that the said THE ONTARIO NICKEL COMMISSION be called and known as ROYAL ONTARIO NICKEL COMMISSION with all the powers conferred by Our Commission aforesaid bearing date the ninth day of September, A.D., 1915.

IN TESTIMONY WHEREOF We have caused these OUR LETTERS to be made PATENT and the GREAT SEAL OF OUR PROVINCE OF ONTARIO to be hereunto affixed:

WITNESS: HIS HONOUR SIR JOHN STRATHEARN HENDRIE, Knight Commander of Our Most Distinguished Order of St. Michael and St. George, Commander of Our Royal Victorian Order, a Colonel in Our Militia of Canada, etc., etc., etc., LIEUTENANT-GOVERNOR OF OUR PROVINCE OF ONTARIO, AT OUR GOVERNMENT HOUSE, in Our City of Toronto, in Our said Province, this nineteenth day of March in the year of Our Lord one thousand nine hundred and seventeen and in the seventh year of Our Reign.

BY COMMAND:

W. D. McPHERSON,
Provincial Secretary.

LETTER OF TRANSMISSION

To the Honourable,

Sir John Strathearn Hendrie, K.C.M.G., etc., etc., etc.,

Lieutenant-Governor of Ontario:—

The Commissioners appointed to inquire into and investigate and report upon the resources, industries and capacities, both present and future, of the Province of Ontario in connection with Nickel and its Ores, and at the same time into and upon a just and equitable system of taxation by the Province of the mines, minerals and mineral industries thereof, as is more fully and particularly set out in the Commission issued to the undersigned under the Great Seal of the Province on the 9th day of September, 1915, have the honour to submit their report.

The Report begins by presenting under the heading "Summary and Conclusions" a brief statement of its contents, and the conclusions at which the Commissioners have arrived on the matters referred to them. The detailed discussion of these matters is contained in fourteen chapters, as follows:—

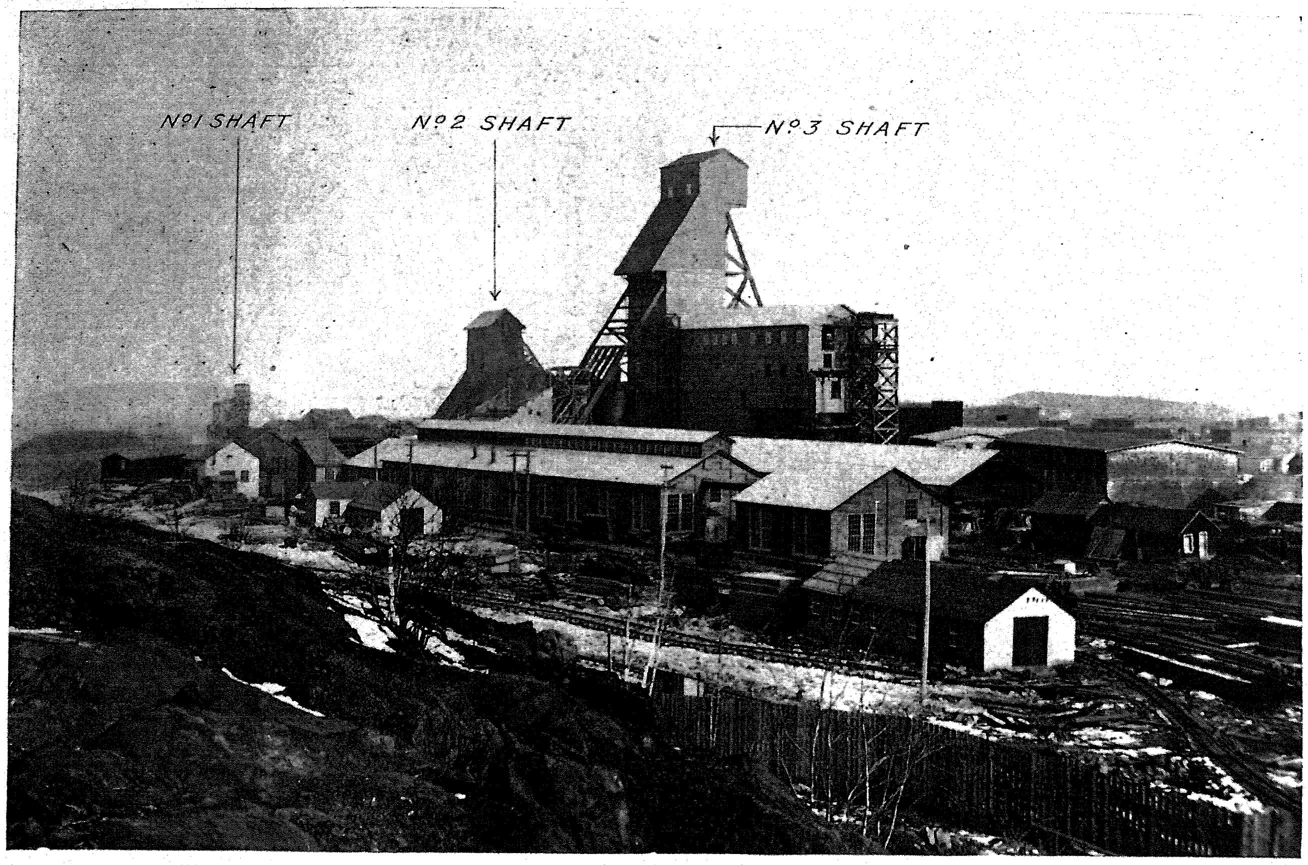
There is an Appendix to the Report, in a separate volume, which contains the testimony of witnesses who appeared before the Commission with regard to the questions under investigation, together with memoranda, written arguments, and other papers submitted by those interested in the Commission's proceedings. A considerable quantity of such material was received, and the Commissioners have exercised their judgment as to what appeared advisable to be printed. Other information of a confidential kind was placed in the possession of the Commissioners, and has had its due influence upon the decisions they reached. In view of its nature and the conditions under which it was received, such information has not been printed.

The whole is herewith respectfully submitted for Your Honour's consideration.

(Signed) George T. Holloway, *Chairman*.
W. G. Miller.
McGregor Young.

Thos. W. Gibson, *Secretary*.
Royal Ontario Nickel Commission.

Toronto, March 19, 1917.



Creighton nickel mine, Sudbury area, Ontario, Nov. 21st, 1916, looking northeastward. The great open pit is to the left of the picture, hidden by the hill in the foreground.

Summary and Conclusions

Introduction

The inquiry into the resources, industries and capacities of the Province in connection with nickel and its ores, directed to be made by the Commission dated the 9th day of September, 1915, was entered upon at once, and prosecuted with diligence.

The Commissioners have endeavoured to equip themselves in a variety of ways for the task of making a satisfactory report. By visiting the working nickel mines in the Province, as well as some of the unworked deposits, by studying geological data, by making inquiry of men qualified by years of experience and work in the nickel industry of Ontario, and by the perusal of reports made by competent investigators who had already worked in the same field, they have sought to obtain a basis for estimating the probable extent of the nickel resources of the Province; and in order that they might be enabled to compare the extent and quality of these resources with valuable nickel deposits in other countries, they have searched the literature of the subject, and availed themselves of information, some of which has not hitherto appeared in print, placed at their disposal by persons who had obtained it at first hand. One of the Commissioners, accompanied by the Chief Inspector of Mines for the Province, visited nickel mines and smelting works in New Caledonia, and obtained much information concerning the industry in that French colony. They also visited the small nickel deposits of Tasmania. A Commissioner and the Secretary visited one of the large deposits of nickeliferous iron ore now being worked in Cuba, as well as other extensive occurrences there lying idle. The Chairman spent about three weeks in Norway, where there are ores similar in composition to those of Sudbury, and where he had an opportunity of examining the operation of the plant in which the Norwegian nickel is refined. The whole Commission spent about two months in England, and during their stay there visited a number of plants manufacturing nickel steel, and using nickel in various forms at Sheffield, Birmingham and elsewhere, nickel refineries at Erdington, Clydach and Swansea, copper refineries at Swansea and Ditton, zinc refineries at Swansea, chemical manufactories at Widnes, numerous chemical and physical laboratories and testing works at London and elsewhere, and held a number of sessions for the taking of testimony from persons engaged in refining and other branches of the nickel industry. They also obtained, at these places and from other sources, much information of interest and value, by means of conversations and interviews. A member of the Commission and the Secretary went to France, and interviewed M. Maurice Carrier, Administrator-Director of La Société le Nickel, regarding the operations of that company, and to pave the way for the visit to New Caledonia mentioned above. At the request of His Majesty's Government, credentials for use in New Caledonia were kindly granted by the Government of France.

While in England, the Commissioners had the advantage of a consultation with the Right Honourable A. Bonar Law, then Secretary of State for the

Colonies, and found that gentleman deeply interested in the question of nickel, and much impressed with the importance of the Ontario deposits, especially for such times of emergency as then existed and still exist. At Mr. Bonar Law's suggestion, the Commissioners subsequently conferred with Mr. C. T. Davis and Mr. E. J. Harding of the Colonial Department, to whom they are indebted for courtesies and assistance. Sir George Perley, acting High Commissioner for Canada, and Mr. W. L. Griffiths, Secretary, freely extended their good offices in the Commissioners' behalf, and much facilitated their communications with the Imperial authorities and in other important quarters. To Mr. Richard Reid, Agent-General in London of the Ontario government, the Commissioners owe their sincere thanks for timely help and guidance.

The Chairman remained in England after the return of the other Commissioners to Canada, to continue his metallurgical and other enquiries and the collection of data, and also to keep in touch with the Colonial Office regarding the special subjects of discussion with that department.

In the United States the Chairman visited and examined the nickel refining works of the International Nickel Company at Bayonne, N.J. (Constable Hook), and the Maryland Steel Company's works at Baltimore, and, with another of the Commissioners, made enquiries as to the utilization of the nickeliferous iron ores of Cuba in the manufacture of nickel steel. The officials of the Federal government at Washington were waited on, and matters of interest pertaining to the industry discussed with them. In New York, two of the Commissioners and the Secretary interviewed, in May last, Mr. W. A. Bostwick, assistant to the President of the International Nickel Company.

One of the Commissioners and the Secretary, with special reference to the question of mining taxation, visited the capital cities of Michigan, Wisconsin and Minnesota, and, from the members of the Tax Commissions of these states, and their officials, obtained much useful data regarding the respective methods of taxation in vogue. They attended the Convention of the National Tax Association at Indianapolis, and received material assistance from experts in taxation there assembled, especially from those representing mining states. Subsequently, the Commission held public meetings at Sudbury, Cobalt and Timmins, where testimony was invited and obtained from persons interested in the inquiry.

All the refineries in Ontario, where nickel and cobalt products are obtained, and all the nickel smelting plants, were visited by members of the Commission and the processes in use inspected.

A large number of witnesses were examined on various aspects of the nickel question, and the evidence taken in shorthand is printed in the Appendix.

The Commissioners are pleased to state that they were everywhere received with courtesy and kindness, and, with few exceptions, every facility was afforded them in obtaining the information they desired. Government officials and others in Great Britain, France and the United States (including the several States of the Union which they visited), Norway, New Caledonia, Australia and other countries, received them with cordiality, and took pains to render their labours effective.

The firms, works and places visited, and the persons to whom the Commissioners are under obligation for information and assistance, are so numerous that it seems advisable to include them in a separate list. This will be found, together with the acknowledgments of the Commissioners, on a later page.

Conclusions

The two questions that have been uppermost in the numerous discussions that have taken place concerning Ontario's nickel industry during the last twenty-five years are: (1) Can nickel be economically refined in Ontario? (2) Are the nickel deposits of Ontario of such a character that this Province can compete successfully as a nickel producer with any other country? It will be seen that the Commissioners have no hesitation in answering both of these questions in the affirmative.

The Commissioners are of opinion:—

1. The nickel ore deposits of Ontario are much more extensive and offer better facilities for the production of nickel at a low cost than do those of any other country. Nickel-bearing ores occur in many parts of the world, but the great extent of the deposits in this Province, their richness and uniformity in metal contents, and the success of the industry, point strongly to the conclusion that Ontario nickel has little to fear from competition.

2. Any of the processes now in use for refining nickel could be successfully worked in Ontario, and conditions and facilities are at least as good in this Province as in any other part of Canada.

3. In view of the fact that practically no chemicals are required, that there is a much more complete saving of the precious metals, especially platinum and palladium, and that electric power is cheap and abundant, the most satisfactory method of refining in Ontario will be the electrolytic.

4. The refining of nickel in Ontario will not only benefit the nickel industry, but will promote the welfare of existing branches of the chemical and metallurgical industries, and lead to the introduction of others.

5. The methods employed at the Ontario plants of the two operating nickel companies are modern and efficient, although there are differences in both mining and smelting practice. It is the consistent policy of both companies to adopt all modern improvements in plant or treatment. Even during the present time of acute pressure the Canadian Copper Company has materially increased its output without substantial enlargement of its plant, and the losses in smelting are less both at Copper Cliff and the Mond plant at Coniston than they were a year ago. These companies have each had their experimental stage, neither has asked nor received any Government assistance, and both have earned the success which they have achieved.

6. The present system of mining taxation in Ontario is just and equitable and in the public interest, and is the best system for this Province. Any question of change is rather one of rate than of principle. This important question is dealt with at length in Chapter XII.

Experiments have been undertaken by the Commission in the production of nickel-copper-steel direct from Sudbury ore, and also in the electrolytic refining of nickel. Certain improvements in the latter process have been made the subject of application, on behalf of the government of Ontario, for patents in Canada, the United States and Great Britain.

Home Refining of Nickel

The opening Chapter of the Report deals with the agitation which has gone on from the beginning of the industry, in favour of the refining of nickel in Ontario. This agitation has at times been very active, and at times less so, but has always been alive. The various steps which Governments and Parliaments have from time to time taken to realize this desire, and the negotiations with the Imperial Government for the same purpose, are summarized.

The Commissioners are gratified at the assured prospect of the erection in Ontario of two large plants for the refining of nickel; one by the International Nickel Company of Canada, Limited, at Port Colborne, and the other by the British America Nickel Corporation, Limited, probably at Sudbury, if a supply of electric power can there be obtained. The development to date as given by these companies is set forth in Chapter III. It may be added that when the Commissioners began their work it was asserted by the companies interested that nickel could not be economically refined in Ontario.

The completion and operation of these plants, especially in view of the probable extension of the facilities now being provided, will go far towards a solution of this question, which has so long exercised the public mind. The output of the home refineries, added to the nickel now being produced in England from Ontario matte, will fully meet, if not surpass, the entire requirements of the British Empire.

There is reason to believe that the cost of refining in the International Nickel Company's new plant at Port Colborne will be less than at their existing works in New Jersey; and if so, the natural tendency will be to enlarge the refining capacity in Ontario from time to time. Provision for doubling or even quadrupling the initial output of 7,500 tons has been made in planning the refinery.

As to compulsory measures for ensuring that the whole of the nickel output of Ontario should be refined within her borders, the Commissioners are advised that the Provincial Legislature has no power to prohibit export or to impose an export tax directly, and the power of the Province in effect to regulate export by differential taxation in favour of nickel refined within the Province is a matter of grave doubt.

The question of a market for nickel ore or low grade or other matte by small producers has received the attention of the Commissioners. Little ore is being mined at present, except by the large companies. Representatives of the British America Corporation have expressed their desire to discuss the subject of custom smelting and refining with the government. An arrangement for custom smelting and refining with this corporation, in which the British government has a controlling interest, should serve all the needs that may arise.

Public Ownership

The suggestion has been made that government ownership would solve many of the questions which have been raised in connection with these deposits. To expropriate the deposits and plants of the Sudbury nickel area would, judging from sales of company shares, probably cost not less than $100,000,000. This is a sum approximately equal to the total paid-up capital stock of all the chartered banks in Canada.

There is no certainty that large profits can be made every year from the nickel industry. The present activity is in part due to well understood causes, which it is to be hoped will never recur. In the past the output has had to be curtailed at times. If the price of nickel should fall, profits will naturally decrease. The nickel industry is to a considerable extent dependent for its success on the highly trained and specialized technical men who superintend it, and who command salaries far beyond those which are paid in the government service to the most highly placed employees. Besides, nickel is not a necessity of life nor an article of universal consumption or use, and the nickel business is in no way comparable to those connected with the operation of public utilities, where government ownership may be beneficial or expedient.

In short, there does not seem to be any good reason why the people of Ontario should be asked to adventure so large a sum of money as would be required for the purchase of the nickel deposits and plants.

Uses of Nickel

The important question of "the demand and market for nickel, its ores and products, by-products and alloys" has called for full investigation of all present and probable uses of nickel in its various forms and alloys.

The uses of nickel are fully described in Chapters V, VI and VII. They may be divided into the following groups:—

1. As a component of alloys. 2. As a surface coating for other metals. 3. As a chemical or catalytic reagent. 4. As pure metal.

Of the alloys, nickel steel, as ordinarily termed, is the most important. It contains about three and one-half per cent. of nickel, has great strength and ductility as compared with carbon steel, and is used in various forms in a wide range of industrial operations, and also in the manufacture of armour-plate, ordnance, projectiles, protective deck plate, gun shields, and many other articles of naval and military equipment.

The properties of toughness it imparts to steel have rendered its use for industrial purposes of increasing importance, and this field has widened very rapidly. As a structural material nickel steel has been employed in the construction of the Manhattan and Queensborough bridges in New York city; in the St. Louis municipal bridge over the Mississippi; in the Kansas City viaduct and bridge over the Missouri; in the emergency dam, locks and spillways in the Panama canal; and in the reconstruction of the Quebec bridge, St. Lawrence river.

Among other uses of nickel steel the following may be cited: For locomotive forgings, electric railway gears, marine engine works, stationary engine construc-

tion, automobile parts (a rapidly increasing use), mill machinery, wire cables, axles and railway rails, especially in tunnels or on curves.

Monel Metal, an invention of the International Nickel Company and named after the president of that company, contains approximately 67 per cent. nickel, 28 per cent. copper, and 5 per cent. manganese and iron. It possesses great incorrodibility and high tensile strength, which have led to its use in many industries. A few of these uses may be mentioned: Propeller blades, valves, castings for oil stills, permanent roofing, tie rods, bolts and nuts, enameling and burning points, shafting and pump rods.

Cupro-Nickel is an alloy of approximately 20 per cent. nickel and 80 per cent. copper. It is largely used in the manufacture of bullet jackets and other munition purposes. Bullet casings contain from 15 to 20 per cent. of nickel, and are used in order to give a surface to the bullet that will not be destroyed by the rifling of the barrel.

Coinage alloys, as a rule, contain about 25 per cent. of nickel and 75 per cent. of copper. This is the material used in the United States five-cent piece or "nickel." It is now usually called nickel-bronze. A novel alloy of 22.5 per cent. nickel, 60 per cent. silver, and 17.5 per cent. zinc is now (1917) being suggested for two new coins of small denomination in connection with the proposed decimalization of British coinage.

Down to 25 per cent. of nickel the copper-nickel alloys are white; with less than twenty-five per cent. they show a reddish-white tint. There are a great number of such copper-nickel alloys used for plumbers' supplies, piping and castings.

Nickel Silver alloys contain from 12 to 25 per cent. nickel alloyed with copper and zinc, say 50 to 66 per cent. of the former, and 20 to 40 per cent. of the latter. They are used for tableware, railway-car fittings etc.

Nickel enters into a great many alloys for electrical use as resistance materials, such as nickel-chromium and nickel-manganese.

The use of nickel in the electroplating of metallic objects is widely known, and requires no explanation. A sheet of iron heated in contact with two sheets of nickel can be rolled so as to produce a perfect nickel coating. This material has been used to a certain extent in Germany for the production of kitchen utensils.

As a finely divided metal, nickel is used as a carrier of hydrogen in the manufacture of fats from oils, and this property of nickel is largely made use of by soap-makers. Nickel oxide is useful for colouring or decolourizing purposes in the manufacture of glass, and there are many chemical uses of nickel and its compounds.

In the pure metallic form nickel is used in the manufacture of sheets which are stamped into watch cases, cigarette cases, cooking utensils, and the like. It is drawn into wire which is often used for spark plugs and electrical leading-in wires. Pure nickel is also employed in some of the European countries for coins of the smaller denominations.

The Commissioners have had the advantage of consulting producers and leading consumers for different purposes in Great Britain and the United States. The opinion is general that the uses of nickel will be extended, and that when normal peace conditions are fully restored, the demand will be greater than it was before the war. A reduction of the price would undoubtedly enlarge the consumption and call for increased production.

Nickel Deposits

In chapter II is given an historical sketch of the early discovery of nickel in Ontario, and of its re-discovery during the construction of the Canadian Pacific Railway, and particulars are given regarding the dates and circumstances of locating the various mines and deposits which form the basis of the industry here.

The Report contains a comprehensive account of the known Nickel Deposits of the World (Chapter IV). Those of Sudbury and New Caledonia are described, and details as to geology, methods of mining, etc., are given. Mention is made of nickel deposits and nickeliferous iron ores in other parts of the world, such as those of Madagascar, Seboekoe (Borneo) and Cuba, some of which have hitherto been but little known.

Competition

The question of competition from other countries is of primary importance.

While competition is not to be feared, it would be futile to try to shut off the supply of nickel from almost any of the great nations. As will be seen from the description of the deposits of the world, nearly every important country has supplies of nickel ore which can be worked if the demand is great, thus ensuring a high price.

In the early years of the development of the Ontario nickel industry grave difficulties were encountered. Of the three pioneer companies, only the Canadian Copper Company has survived. The chief difficulties were the economical treatment of the ore, the prejudice of the trade against Canadian nickel, and the limited market. Gradually, and not easily, the obstacles were overcome, and from a weak and precarious infancy, the Sudbury nickel industry has grown to be one of the great metal industries of the world. The market for nickel is much more restricted than for iron, copper, and other so-called common metals. Production has to be more closely considered in relation to consumption. Statistics show that at certain periods the output of nickel from Sudbury ores has not shown a normal increase; it has occasionally decreased. This has been chiefly due to the fact that consumption has not kept pace with production. Much has been done by the refiners of Ontario nickel by means of advertising and research to increase consumption and to enlarge the markets.

The proven, or positive, ore of the Sudbury area can be conservatively put at 70 million tons, while it is safe to say that the proven, together with the probable and possible ore supply, exceeds 150 million tons. The International Nickel Company's published estimate of their ore reserves is 57 million tons, which is for three mines only. Although the Sudbury deposits have been worked for twenty-nine years, there is vastly more ore proven in the district to-day than there was five years ago.

In the last few years the proven reserves in the Creighton, Frood, and Crean Hill mines of the Canadian Copper Company (International Nickel Company) have been very largely increased. The historic Copper Cliff mine is not exhausted, but is lying dormant simply because the company can mine ore more cheaply from other properties.

Of the Mond Nickel Company's properties, neither the Victoria, the oldest mine of this company and the deepest mine of any kind in Ontario, nor the Garson,

another of its older mines, shows signs of exhaustion. The great Levack property has been developed only within the last three or four years into a mine now known to have at least 4,500,000 tons of ore, and it may be added that the ore of this mine has been found to be of higher grade than was thought to be the case in any of the properties in the north nickel range. The Worthington mine, that lay unworked for years, has lately been reopened and possesses important reserves.

The Murray mine, now owned by the British America Nickel Corporation, was operated in the early years of the nickel industry in Sudbury and thought to be of little importance. This mine lies right on the main line of the Canadian Pacific Railway, three miles from Sudbury, and is one of the best examples that can be cited of a great mine lying for years, after its discovery and after considerable work had been done on it, with its importance unrecognized. Several companies had options on it at various times after the Vivians ceased work over twenty years ago, but it is within only the last four or five years that its greatness has been determined. Diamond drilling has proved that it and the adjoining Elsie property contain at least 8,500,000 tons of ore.

The apparently important discovery by the Longyear syndicate, during the last few months, of nickel ore bodies underlying the heavy covering of drift in the township of Falconbridge, east of the Garson mine, should also be mentioned. The discovery was made by means of diamond drills and proves, what the geological conditions would suggest, that not all the nickel deposits of the district are exposed at the surface.

The existence of the Alexo mine, Timiskaming district, in actual operation, so far from Sudbury, is significant of possibilities outside of that area.

No such vast deposits of workable ores, considered as a source of metallic nickel, are known in any other country, and there is no reason to believe that any competition will arise with which Ontario cannot cope.

The sources of competition are discussed in the Chapter on the Nickel Deposits of the World.

The competition of New Caledonia calls for special mention. The question has received careful consideration from the Commission, and in view of its importance, one of the Commissioners, accompanied by the Chief Inspector of Mines, visited and spent some time on the island, where by the courtesy of the French government and the officials of the operating companies, they were able to secure first-hand information in regard to its resources and prospects.

For many years New Caledonia dominated the nickel market of the world. With its accumulated experience, the financial support of the Rothschilds, a trade prejudice in favour of its product, and long and favoured connections with the principal consumers in Great Britain and elsewhere in Europe before and after the advent of Ontario as a producer, New Caledonia has been unable to keep pace with her younger rival.

When the Sudbury industry began, practically the whole of the world's demand for nickel was supplied from New Caledonia. In 1900 about 65 per cent. of the world's nickel came from New Caledonia and about 35 per cent. from Canada. The world's output has increased fivefold since that time, and Ontario now produces over

80 per cent. of the whole. The production of Ontario in the last 15 years has increased ninefold; the production of New Caledonia by less than 20 per cent.

The chief factor that has enabled Sudbury to outdistance its only serious rival is the difference in the size of the ore bodies in the two countries. The principal Ontario deposits contain ore that is measured in tonnages of millions, while those of New Caledonia are reckoned in a few hundreds of thousands. The greatest of her deposits contained about 600,000 tons; few reached 250,000.

A determination of the ore reserves in New Caledonia is not possible owing to their uncertain character, but it is probably fair to say that the colony possesses at least as much high grade ore as she has already mined in the forty years of her existence as a producer. This would give a total of say 160,000 tons of metal, which would represent about four years' output from Sudbury at the present rate of production.

There being many deposits for selection, the first mines to be worked were naturally the most accessible, and usually those near a harbour. Many mines that were once worked are now abandoned, including the Bornet, which has the record of having been the largest producer. The production of the larger mines is decreasing, and mines such as the Emma in more inaccessible situations are now being opened, necessitating the extension of the railways farther into the interior of the island. There is no evidence to show that any of the new nickel mines are larger than some of the old ones, or that ore can be produced more cheaply from them.

The essence of the whole matter in so far as competition from New Caledonia in the open market is concerned, is the cost of the refined nickel produced from its ores. More than a dozen years ago the cost was approximately 19 cents a pound. Immediately prior to the war it had not been lowered. At present with excessive freight rates and increased prices for supplies, the cost is much increased. As long as the price of nickel remains about the same as it has been during recent years, New Caledonia will have an important industry. It will probably expand to some extent, owing especially to the activities of the newer of the two companies that are shipping ore and smelting on the island. But there is no good reason for believing that the competition with Ontario will become any stronger than it has been in the past. Should the price of nickel fall to 25 cents a pound or less, New Caledonia will have difficulty in keeping her mines in operation.

While it is true that Ontario has no monopoly it posessses many advantages over all competitors, even under the present conditions of the market as to prices and trade connections. In any keen competition as to prices it is doubtful whether any other locality at present known or suggested could compete with Ontario. It is a matter of record that at one time of low prices the leading New Caledonia company was compelled to suspend all dividends. It may be doubted, further, whether anything but an arrangement of the market between the great interests can prevent the complete domination of the world's trade by the nickel industry of Ontario making the best use of its exceptional resources.

A Chapter of the Report is devoted to the history and development of the principal operating companies connected with the industry in Ontario from its inception.

Refining Processes

There are three processes, which may be described as standard methods, in use for the refining of nickel from ores like those of Sudbury. These are (1) the Orford process, employed for the treatment of the matte produced by the Canadian Copper Company, (2) the Mond process, and (3) the Electrolytic process. For all these processes, the production of a matte is essential. Matte is made by substantially the same method for all three.

The Orford Process is the oldest of the three. It is cheap to operate, and permits of a large output in a confined space, but it does not recover more than a small proportion of the precious metals present in the ores, and there is reason to think that losses of nickel and copper are heavier than in either of the other two processes.

In the Orford process, the matte is smelted with sodium sulphate and carbonaceous matter, such as coal or coke, so that a large proportion of the copper is separated as a double sulphide of copper and sodium, when tapped from the furnace: this separates as an upper layer above a matte which is much richer in nickel and poorer in copper than the original matte. A repetition of the smelting of this highly nickeliferous matte results in a further separation of copper in the same way, so that finally, the bulk of the copper is obtained as a slag (which is smelted to produce blister copper) together with a matte so rich in nickel and so poor in copper that, after being roasted and leached with acid, to remove the remainder of the copper which it contains, it can be smelted in a reverberatory furnace, for the production of metallic nickel. The leaching processes result in the production of a considerable amount of copper sulphate and nickel sulphate. The former is treated for the production of metallic copper, but the latter is, to a considerable extent, crystallized out, and either treated electrolytically for the production of high grade electrolytic nickel, or sold as nickel sulphate or as the double sulphate of nickel and ammonium for electro-plating and other purposes.

The Orford process, being partly chemical, produces large quantities of noxious effluents. At the Bayonne works over 150 million gallons are annually run into the sea. The plans for the new works at Port Colborne, Ontario, provide for the elimination of this discharge.

The Mond Process treats a matte of somewhat different composition, because, although it contains about the same total quantity of nickel and copper, the relative proportions of the two are very different. The matte from the Canadian Copper Company averages about 54 per cent. nickel and 25 per cent. copper, whereas that from the Mond Nickel Company is much richer in copper and averages about 41 per cent. nickel and 41 per cent. copper. These differences are due to the composition of the ores treated by the two companies. The matte is refined at Clydach in Wales. In this process there are probably the smallest losses either of nickel, copper, or the precious metals.

The process comprises roasting to remove the sulphur, leaching with sulphuric acid to obtain a large proportion of the copper, which is ultimately crystallized out and sold as copper sulphate, and the reduction of the oxides of nickel together with the small quantity of copper left in the roasted and leached matte with pro-

ducer gas, which reduces the iron, copper and nickel to the form of finely divided metal. This material is next treated in a vertical chamber or tower with producer gas at a special temperature, by means of which the nickel is converted into a volatile compound known as nickel carbonyl. This passes to another chamber or tower, where it is exposed to a higher temperature, whereby it is decomposed so that the metallic nickel is deposited on a number of slowly descending grains of nickel previously added in the form of small shot. The residues from the first treatment are either again treated with sulphuric acid to remove the copper and iron, or are smelted again, after which the nickel they contain is recovered by repetition of the treatment. The residues are finally separated and sold for their precious metal contents. The nickel produced is of high purity, and has an excellent reputation.

It may be mentioned that the leaching described as being done upon the original roasted matte, dissolves a considerable quantity of nickel as well as of copper. This is recovered and sold as nickel sulphate, or as nickel ammonium sulphate, for electro-plating and other purposes. The Mond Nickel Company does not make or sell any metallic copper.

The Hybinette Process, employed in Norway, and about to be employed in Ontario by the British America Nickel Corporation, deposits the nickel electrolytically, using soluble anodes made from partly roasted nickel copper matte. The copper is obtained as a crude blister copper, by treating it with the scrap anodes from the electrolytic nickel production. The copper thus produced is melted into anodes and electrolytically purified. Without going into details, it may be stated that the Hybinette and other electrolytic processes produce nickel and copper of high quality and with small losses, and that they recover the bulk of the precious metals.

One great advantage of the electrolytic process is that although the plant occupies considerable space, it can be erected at short notice, and units can be added to the plant, to any extent, as the output requires.

No attempt is at present made in working any of the above-described processes to recover the sulphur, which all goes to waste as fumes, except a small portion which, in the electrolytic method, becomes converted into sulphuric acid and is used as such in the process.

A large number of other processes, many of which are feasible and some of which may become commercially workable, have been proposed; but the whole question of Refining is fully dealt with in Chapter IX.

Hydro-Electric Power

The Province of Ontario is fortunate in possessing an abundance of water power. In the absence of coal mines this is a feature of great importance in connection with her mining and mineral industries. In the "Water Powers of Canada," (1916), published by the Dominion Water Power Branch, Department of the Interior, Ottawa, the following estimate of the available water power in Ontario, and the amount of power so far developed, is given by Mr. H. G. Acres, hydraulic engineer, Hydro-Electric Commission of Ontario.

Division.	*Potential H.P.*	*Developed H.P.*
Ottawa River and tributaries	688,000	71,000
Great Lakes tributaries	146,000	137,000
Hudson Bay slope	250,000	22,000
James Bay slope	1,500,000	30,000
International Boundary waters	2,045,000	462,000
	4,929,000	722,000

For electric furnace work and the manufacture of chemicals, electric power has come into extensive use, by reason both of the high temperatures it is capable of producing, and the power it possesses of dissociating compounds by electrolysis. Particularly is the electric current rapidly taking over the field for the manufacture of special metals and alloys, such as metallic aluminium and ferro-alloys, including ferro-chrome, ferro-molybdenum, ferro-tungsten, ferro-nickel and ferro-silicon. Where the current is cheap, it is also being successfully employed in the direct smelting of ores, including those of copper and, in Sweden, iron ores for the manufacture of Swedish charcoal-iron and steel. The great advantage of the electric furnace is the absolute control which can be exercised as regards the output, the extra purity of the products, and the possibility of desulphurizing and otherwise purifying the first product by return to the furnace with the necessary reagents or fluxes.

The scale upon which electric power is now utilized in electro-chemical and electro-metallurgical manufactures is strikingly illustrated by the great development of such industries in the neighbourhood of Niagara Falls, on both sides of the boundary line. This concentration is wholly due to the cheap electric power generated from the great cataract.

Further, in every important mining camp in Ontario hydro-electric power is in use for mining, treatment and all other purposes at a cost of about one-third that of power produced from either coal or wood.

A description of the power plants of the Canadian Copper Company and the Mond Nickel Company is given in Chapter IV of this Report, under the heading "Methods of Mining," and a concise and interesting review of the hydro-electric developments and possibilities of the Province and their relations to the mining and refining industries, by Mr. H. G. Acres, will be found in the Appendix under the heading "Ontario Water Power and the Mining Industry" (Section F). The schedules there printed, which were furnished by Mr. R. T. Jeffery, show the cost of electric current in various parts of the United States and elsewhere, in comparison with the cost in Ontario, greatly to the advantage of the latter.

The special bearing of this abundant and cheap supply of water power on the nickel industry, consists not only in the use of electric energy generated therefrom in the operation of mines, smelters, etc., but also in the fact that it enables the electrolytic method of refining nickel to be employed under advantageous conditions as to cost. The Hybinette electrolytic process is the one adopted by the British America Nickel Corporation for the refinery it is to erect at Murray Mine.

In the Appendix, under the title "Water Power Development in Norway," a brief history is given of the development of water power in that country. This is rendered interesting owing to the resemblance between Norway and Ontario in climatic and other conditions, and in the fact that both countries are without coal.

Costs of Refining

There are three steps in the production of refined nickel, namely, mining, smelting and refining. Heretofore as regards the Sudbury industry, only mining and smelting have been done in this country, the Mond Company refining in Wales, and the International Company, of which the Canadian Copper Company is the Ontario branch, in New Jersey.

The Mond Company have furnished the Commissioners, confidentially, a complete statement as to the costs in each of the three stages; the International Nickel Company have furnished a statement of costs for mining and smelting, but have declined to furnish costs for the third stage, namely, refining. The British America Nickel Company, now beginning operations in Sudbury, have supplied an estimate as to cost of refining nickel by their process, as well as the cost of operation of this process in Norway, where it has been employed for some years.

Regarding processes and costs of refining nickel, the enquiries made by the Commissioners have led them to the following conclusions:—

The respective costs of producing refined nickel from the Sudbury ores by each of the three processes mentioned do not differ to such an extent as to give any one process a material advantage over the others in competition.

An electrolytic process has been a commercial success on lower grade ores in Norway. The use of electrolytic processes by all the companies operating in Ontario would not prevent their meeting competition from any other quarter.

The costs of production are gradually falling through increased efficiency and larger output, and may be still further reduced. War conditions, resulting in scarcity of labour and increased cost of supplies, are for the present exercising an influence in the opposite direction.

The International Nickel Company, until recently, contended on commercial grounds that the Orford process could not be profitably operated in this Province. These contentions were largely based on comparative costs as between New Jersey and Copper Cliff. Evidently they do not now apply to the north shore of Lake Erie, where, at Port Colborne, this company is building a refinery.

The Mond Nickel Company allege that by reason of the greater expense due to higher wages, increased cost of fuel and chemicals, and higher freight charges, refining in Ontario would make a material addition to the cost of their products, namely refined nickel and sulphate of copper. The company have supplied the Commission with figures in support of this view. A special argument is based upon the necessity of quick delivery for copper sulphate, which is marketed in the vine-growing countries of the Mediterranean, and is required only during a limited season of the year for destroying blight on vines. A concise statement of the reasons the company have urged before the Commission will be found in a memorandum submitted by them, and printed in Section "I" of the Appendix.

There is nothing to prevent the Hybinette process, of the British America Corporation, being operated as cheaply and as efficiently in Ontario as elsewhere. The costs at Sudbury will be less than they have been in Norway, owing to the larger scale of the operations in Ontario.

Nickel-Copper Steel

The possibility of utilizing the iron in the Sudbury ores by direct smelting has always been recognized. This iron, amounting to say 40 or 45 per cent. of the weight of the ore, is now wholly lost in the present processes of treatment: and the practical solution of the metallurgical and commercial problems involved in utilizing the iron would conserve our resources and add to our industries.

The steel might be made either from the raw or roasted ore, or from the slag which would contain both nickel and copper, together with nearly all the iron originally present in the ore. Taking a typical Sudbury waste slag as an example, there is a theoretical possibility of obtaining from one million tons (about two-thirds of the 1916 production) over 100,000 tons of nickeliferous pig, containing 3,000 tons of nickel and 2,500 tons of copper.

It may be added that in the production of nickel-copper steel direct from the Sudbury ores, the precious metals (gold, silver, platinum and palladium) will be entirely lost. If it should prove practicable to use the slag, instead of the ore, as the source of nickel-copper steel, this objection will not obtain.

There is a trade prejudice against the presence of copper in steel, which it would be necessary to overcome. This prejudice does not appear to be justified, and seems to be lessening. Much independent research work has been published on the subject, and the results are presented in Chapter VII of the Report. The conclusion is reached that the presence of copper within limits available when using the Sudbury ores or slags, is not objectionable and may be a benefit.

In view of the practical importance of the question, the Commissioners obtained the services of Mr. G. A. Guess, Professor of Metallurgy in the University of Toronto, to make experiments in the production of nickel-copper steel direct from Sudbury ore, and also to investigate the quality of nickel steels containing copper.

Professor Guess produced a series of 3½ per cent. copper-nickel steels, with varying ratios of copper to nickel, in order to study their properties. The steels were forged by the John Whitfield Company of Toronto and found to be of good quality. The percentages of nickel varied from 1.8 to 3.43, and the copper from 1.3 to 0.03. In concluding the description of his experiments Professor Guess says: "The value of this process of producing nickel-copper steel is based on the belief that copper may replace a very considerable amount of the nickel in a 3.5 per cent. nickel steel without producing an inferior article, which belief is, I think, well founded." Details concerning the experiments are given in Chapter VII.

Nickel Statistics

The Commissioners have endeavoured to obtain reliable statistics both of production of nickel and its consumption for the different uses in which it is employed. On account of the fact that the prevailing practice is to refine nickel in countries other than the country of origin, it is not possible to procure absolutely complete and satisfactory figures. There is confusion and frequently duplication, by reason of the statistics of export and import being given for differing fiscal years; ore or matte must be converted into terms of nickel on an assumed basis, and in many instances, statistical authorities differ among them-

selves. Further, the figures annually obtained and published are those of the estimated contents of the ore and matte exported, and no allowance is made for losses in refining.

Notwithstanding these difficulties, the statistics presented in Chapter XII dealing specially with the subject, may be regarded as fairly correct for the production of nickel, at any rate for the two main sources, New Caledonia and Ontario, and also for Norway.

It is unnecessary to recapitulate the figures here, but a perusal of them will convince anyone of the fact that at the present time the position of Ontario as the world's leading source of nickel is indisputable. This position has not been won without a struggle, which especially at the beginning was severe. It should be realized that this position is maintained not merely by virtue of the size and quality of the deposits, and the proximity of the markets of the United States and Europe, but also by the care and skill which the successful companies have exercised in the management and working of their mines. In times like the present, when demand is imperative and prices high, these latter qualities may not seem so important, but seasons of depression have occurred in the past and will recur in the future, when close economy and a high order of technical ability will be required.

Figures showing the imports and exports of nickel as regards the United States are also given. That country is a very large user, and at present the largest refiner, of nickel. Her imports consist almost wholly of unrefined material, practically of matte only, since the transportation charges on crude ore from any available source of supply would be excessive. Ore and matte are admitted free of duty, but refined nickel is dutiable at the rate of 10 per cent. ad valorem. The United States is not without deposits of nickel ore within her own boundaries, but so far no ore bodies comparable to those of Ontario have been found. It would quite accord with the tariff policy of the United States, should her domestic sources of nickel supply continue insufficient for her needs, to reduce or wholly abolish an import tax which increases the cost of manufactured articles for which nickel is required.

Interesting statistics have been furnished by the International Nickel Company showing by years and countries the shipments of nickel by that company for the ten years preceding the present war, and also of the shipments since the war began. These will be found in Chapter III, dealing with the Operating Nickel Companies.

Satisfactory information as regards the exports and imports of Germany are not obtainable for recent years. Such figures as can be had do not agree.

Germany's own mines, normally, give a very small production; but that country before the war was a large refiner of ore and matte, principally from New Caledonia, also a large importer of refined nickel from the United States, and to a much smaller extent from England. In the latter country it had practically obtained control of the market for certain minor articles. According to the British Diplomatic and Consular Report, the quantity of New Caledonia ore imported into Germany in 1912 was 13,423 metric tons; in 1913 it was 7,906 tons. According to the Mineral Industry, the total imports into Germany in the first half of 1914 were 13,042 metric tons of nickel ore and 1,066 metric tons of nickel

The imports of cobalt and nickel ores are given as 14,987 tons in 1912 and 13,658 tons in 1913, while the figures for metallic nickel imported in these years are 2,027 and 3,315 tons respectively. It is difficult to determine the quantity of nickel that has been produced from ores mined in Germany. In statistics available the quantity of nickel ore is not given separately, but with those of cobalt and bismuth. The ores of these three metals produced in 1912 amounted to 12,861 tons, while the production of nickel ore in Prussia alone is given at 12,091 tons in 1912 and 13,538 tons in 1913. Doubtless much more nickel ore has been mined in Germany since the war began.

The quantity of ore and matte from New Caledonia imported by Great Britain, France and other countries are given in that part of Chapter IV devoted to New Caledonia. Statistics as to production in various countries are given in connection with the description of the ore bodies.

Nickel as a By-Product

Although most of the nickel of commerce is obtained by the direct smelting of nickel ores, a considerable quantity, but small in proportion to the whole output, is obtained as a by-product from the treatment of such ores as those of the Cobalt district, from the refining of "blister," i.e., crude metallic copper, and from the working-up of waste metal, etc. The copper from some districts is much richer in nickel than that from others, but there are few important works where blister copper does not yield nickel during refining. The ore from the Katanga district, Belgian Congo, South Africa, contains nickel as well as cobalt. Prior to the war, large quantities of blister copper, stated to contain about 3 per cent. of cobalt and nickel, were sent from there for refining to Germany, where the cobalt and nickel and the precious metals were recovered. One estimate indicates that Germany obtained about 800 tons of nickel and cobalt in a single year from ore from this source.

A considerable quantity of nickel is obtained in the electrolytic refining of blister copper in the United States. There are, in the vicinity of New York, nine large refineries which in 1914 had a total capacity of 889,000 tons of copper, the smallest having a capacity of about 24,000 tons and the largest about 200,000 tons. According to United States government statistics, approximately 423 short tons of nickel were produced in that country in copper refineries in 1914, and 822 tons in 1915. Owing to the difficulty of collecting such statistics, these quantities are doubtless too low. The marked increase in the copper production of the United States during the present war will correspondingly increase the quantity of by-product nickel obtained.

There is also an unknown quantity of nickel obtained from the treatment of waste or scrap metals. The quantity of metal thus returned into circulation every year, either as pure nickel or in the form of alloys, is probably more than that obtained by the refining of blister copper.

Price of Nickel

At about the time mining began in New Caledonia, in 1875, the price of nickel, according to a report made to the government of France, was 18 francs a

kilogram ($1.58 per lb.). It fell successively to 10 francs, 5 francs (1892), 4 francs (1894), 3 francs (1895), and, owing to Canadian competition, to 2.40 francs a kilogram (21 cents per lb.) at the end of 1895. In 1902 the price was between 3.50 and 4.00 francs a kilogram (30 to 35 cents per lb.). During recent years the price has been about the same. A higher price has been charged in selling small quantities, and at times a considerably lower price for large quantities on long-term contracts.

The Commissioners were informed by the British Government in May last that it was obtaining all its supplies from four companies at £175 sterling per long ton. This is equal to 38.8c. per lb. The ruling price in England was then £225 sterling, about 49c. per lb. Prior to the war the price to the British government was £160 sterling per ton (34.8c.); on the other hand, a user in Birmingham stated that in May, 1916, he was purchasing in five-ton lots at £200 per ton (43½c.), and that the steelmakers paid less. Henry Wiggin and Company, Limited, of Birmingham, quoted before the war, in September, 1913, £165 per ton for hundred-ton lots, rising to £171 per ton for lots under five tons, or 1s. 8d. per lb. for smaller lots.

Since the war began there has been an increase in price, but not a large one compared with other metals, little, if anything, more than sufficient to cover the increase in cost of labour, freight and insurance. The influence of long-term contracts, upon which nickel is usually sold, has no doubt tended, along with the elimination of Germany as a market, to keep down the price.

Reference may be made to the evidence of Sir Alfred Mond, which will be found in the Appendix, that there was no arrangement between the producing companies for the regulation of prices or the division of the markets.

The statistics of value placed upon the nickel and copper contents of the matte in the returns of the producers to the Ontario Bureau of Mines, are merely nominal, being for the Canadian Copper Company, 10 cents per pound for nickel and 7 cents for copper, and for the Mond Nickel Company, 15 cents for nickel and 7½ cents for copper. These figures remain stationary from year to year, not fluctuating with changes in the prices of the metals. In the case of the Canadian Copper Company, they appear to have been adopted because they represent the price at which the company sold the matte to the Orford Copper Company before both concerns were merged into the International Nickel Company in 1902. The practical effect is to credit the entire profits of the business to the refining stage, and to eliminate them from the mining and smelting stages. This is a convenient method for the companies, since no real change of ownership takes place between the mine and the finished metal. The result, however, is to unduly depress the figures of value in the Ontario statistics, and in dealing with the figures for 1915 the Bureau of Mines adopted a valuation of 25 cents per pound for nickel and 10 cents for copper in the matte. The latter figure has been increased to 18½ cents for 1916, since the price of refined copper has risen to a height not hitherto approached during the last forty years.

Losses in Mining, Smelting and Refining

The losses in each department are considerable, but in mining and smelting, at any rate, they are well recognized by the two large operating companies. It may be taken for granted from what the Commissioners have seen of the efficient working of these companies, and from the analyses supplied, that everything is being done to minimize these losses, so far as meets the requirements of companies having large quantities of rich ore for immediate use and in reserve, and very large supplies of low-grade ore proved and ready for working when needed.

As to losses in refining, it may be said that there is more room for improvement in the treatment of a matte containing about 80 per cent. of metals, nickel and copper, than in the simple production of such matte.

The losses on the roast-heaps through leaching are not definitely known, although they have been estimated by the Canadian Copper Company at about 1½ per cent. of the total copper and nickel.

In addition to losses in mining, and the leaching losses on the roast-heaps, the losses by the Canadian Copper Company in the slags from the smelting at Copper Cliff amounted in the year ending March 31, 1916, to about 8.9 per cent. of the total nickel, and about 9.6 per cent. of the total copper. Although their work is carried on with great efficiency, and it is not suggested that these losses can be reduced, the total, reckoned on 1,227,187 tons of ore raised in 1916, reaching, as it does, 3,100 tons of nickel and 1,400 tons of copper per annum, indicates the importance of any improvement which can be made in metallurgical practice.

The smelting losses of the Mond Nickel Company may be taken as similar, except that their roast-heap losses are less, as they employ heap-roasting to a much smaller extent.

The Commissioners have to express their appreciation of the frankness with which both companies have discussed the question of losses, and their willingness to consider any possible means of lessening them. They point out, however, and the Commissioners agree, that there is no reason to anticipate much further saving on smelting operations, and that the losses in the smelting of nickel-copper ores are always likely to be greater than those inherent in ordinary copper smelting, with which the treatment of the Sudbury ore is fairly comparable.

The losses in mining will be gradually reduced as the grade of ore mined becomes lower. That processes of flotation will in the future be applied to the Sudbury ores there is good reason to expect, and it is most probable that such processes will enable a larger proportion of nickel to be obtained from a given mine than at present. This will be effected, however, rather by making it possible to treat low grade ores necessarily or conveniently raised while extracting those of better grade, than by stopping actual leaks now existing in any of the stages of treatment. These leaner ores are now left in the mine, or in some cases are stored in dumps, but as the cost of obtaining them is small, being largely covered by that of mining the better ores, they could probably stand the additional expense of concentrating by flotation. A positive gain of this kind is as beneficial as an improvement in metallurgical processes for the prevention of actual smelting and refining losses, and is quite in keeping with the tendency of modern metallurgical methods.

It may be added that although the amount of nickel and copper varies from time to time in the different deposits, the average of the ore from the several mines has not shown any serious falling off. The copper may have increased relatively to the nickel, or the reverse may have been the case, but any increase in the amount of copper, so far as the Canadian Copper Company's deposits are concerned, appears to have been due to the inclusion of more rock matter, which is richer in cupriferous mineral than the massive ore. The whole of the Sudbury deposits have shown wonderful continuity, and the ratio of nickel to copper, commonly given for the whole field as two to one, is remarkably near the truth. The Mond Nickel Company's ore averages more nearly one to one, but this is due to the fact that the company has acquired properties which are inherently richer in copper than nickel, and that it is actually desirous of having a larger proportion of copper in their ore, on account of the ready sale of the copper sulphate, which is one of the primary products of its process, as contrasted with that of the International Nickel Company.

Sulphur Fumes

A Chapter of the Report is devoted to the discharge of sulphur, in the form of sulphurous acid, in roasting, smelting and refining the Sudbury ores. While the subject has received attention from the operating companies, it has not been found possible to make any economic use of the large quantities of sulphur that are thus wasted. Attempts are constantly being made to minimize the damage caused by the escape of sulphur. It is believed that in the not distant future smelting methods will be developed that will do away with conditions that now exist.

The roast heaps are the worst offenders both in quantity and in injurious results. Roasting during the winter months is less harmful than at any other season of the year. The Mond Nickel Company is not now roasting during the summer months, and is making arrangements with a view of discontinuing roast heap practice altogether if possible. The British America Nickel Corporation does not intend to use roast heaps. The Canadian Copper Company has roast heaps continuously in operation carrying a total of about 250,000 tons of ore. The injurious effects will be considerably lessened by the recent change in location of the roast yard. Apart from the question of nuisance and injury, the roasting of the ore in heaps is not the best or most efficient metallurgical practice, and involves unavoidable losses of both nickel and copper. The sulphur driven off at the roast heaps, amounting to over half of the total discharge, cannot be recovered. The Commission estimates that the total yearly discharges from the heaps, smelters and refineries, is not less than 300,000 tons of sulphur discharged in the form of sulphurous acid gas, and capable of producing nearly a million tons of ordinary sulphuric acid. This is equal to about one-quarter of the total annual consumption of the United States, of which one-fourth (1 million tons) is produced from the discharged gases from smelters, and exceeds all probable requirements of Canada for many years.

In other countries the recovery of sulphur and other noxious gases has ultimately resulted in the development of important industries. Sulphurous acid gas could be utilized direct in pulpmaking and other industries, but the present con-

ditions are not favourable for such use, owing to the distance of such plants from Sudbury. Freight charges on sulphuric acid to points of consumption are considered to be too great to permit of the development of this industry at present. The most desirable method of recovering the sulphur, if feasible, would be as free sulphur, which can be easily transported and for which there is a good demand.

Precious Metals

The Sudbury ores contain minute quantities of the precious metals. Besides gold and silver, these include platinum, palladium and other rarer members of the platinum group. The ores cannot be profitably treated for these metals alone, but the smelting process automatically concentrates them in the matte, and thus makes it practicable to recover them. The subject is dealt with in Chapter X under the title, Recovery of the Metals of the Platinum Group.

In view of the usefulness and scarcity of platinum, the supply of which is being eked out by substituting palladium wherever the latter is suitable, every source of the metal is worthy of investigation, and every effort should be made within economic limits to obtain it.

Trade Conditions

The demands and markets for nickel are discussed in various Chapters throughout the Report. Prior to the war nickel was sold like any other metal to any country in which there was a market for it, and it was treated solely as an article of commerce without regard to international relations. The Commissioners found no evidence of any arrangement for dividing the markets between the great producing companies, although the International Nickel Company has the benefit of the United States duty on imports against its competitors.

The great French company, La Société le Nickel, had a branch works in Germany at which it refined part of its New Caledonia output. The whole of the Norwegian supply of metal has been sent to Germany during the war. In the United States, where by far the greater part of the nickel refined is of Canadian origin, considerable nickel is produced from New Caledonia matte and as a by-product from the refining of crude copper, and scrap metal containing nickel is also available. Almost every great power has deposits of nickel ores which can be worked when the price of the metal is sufficiently high, and from which its requirements in time of war could largely be secured.

There has been much discussion concerning the possibility of Canadian nickel reaching enemy countries during the war. While the question is not within the jurisdiction of the Commissioners, it was referred to in the conferences with officials of the Imperial Government. For reasons of public policy the measures taken by the Government in regard to nickel, copper, rubber and other contraband materials cannot be disclosed.

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Governments, Departments and Institutions

Governments of France, Russia and Norway.

GREAT BRITAIN

London: French Embassy; Russian Embassy; United States Embassy; Board of Trade; The Colonial Office; The Foreign Office; Home Office; Ministry of Munitions; Office of the High Commissioner for Canada; Office of the Agent-General for Ontario; Engineering Standards Committee; Government Laboratory; Imperial Institute; Institute of Chemistry; Institute of Metals; Institution of Civil Engineers; Institution of Electrical Engineers; Institution of Mining and Metallurgy; Iron and Steel Institute; National Physical Laboratory; Royal Colonial Institute; The Royal Mint; Royal Societies Club; Society of Chemical Industry.

Sheffield: Assay Office.

NORWAY

British Legations and Consulates at Kristiania, Kristianssands, Arendal, Bergen; French Legation, Kristiania.

UNITED STATES

Washington, D.C.: Bureau of Mines; Bureau of Standards, Carnegie Geophysical Laboratory; Smithsonian Institution; United States Geological Survey Office.

Baltimore, Md.: Maryland Geological Survey.

New York, N.Y.: American Institute of Mining Engineers; American Society of Mechanical Engineers; Columbia University: Engineers' Club.

Lansing, Mich.: State Geologist; State Tax Commission.

Madison, Wis.: State Geologist; State Tax Commission.

St. Paul, Minn.: State Tax Commission.

CANADA

Ottawa, Ont.: Canadian Munition Resources Commission; Imperial Munitions Board; Mines Branch; The Mint.

Montreal, Que.: McGill University (Prof. A. Stansfield).

Toronto, Ont.: Canadian Mining Institute (Branch); Engineers' Club; Inspectors of Mines; Provincial Assay Office; University of Toronto.

AUSTRALIA

Sydney: His Excellency the Governor of New South Wales; Government Geologist of New South Wales.

Melbourne: Canadian Trade Commissioner.

Adelaide: Government Geologist of South Australia.

NEW CALEDONIA

Nouméa: His Excellency the Governor of New Caledonia; His Majesty's Consul.

Companies and Firms

FRANCE

Paris: La Société Anonyme le Nickel.

NORWAY

Arendal: A/S Almendeleg Elektrokemik; Norske Nitrad A/S Eydehavn.

Kristianssands and Kristiania: Nikkelraffineringsverk.

Odda. Alby United Carbide Factories, Limited; North-Western Cyanamide Company.

Tysso: Tyssefaldene.

GREAT BRITAIN

Clydach: The Mond Nickel Company, Limited (also London).

Swansea: Anglo-French Nickel Company, Limited (also London); English Crown Spelter Company, Limited.

Llansamlet: Swansea Vale Zinc Company, Limited.

London: Dundas Cuni Mining Company, Limited (also Tasmania); Hall Motor Fuel, Limited; Johnson, Matthey & Company, Limited; Daniel C. Griffith & Company.

Birmingham. The Nickel Company, Erdington; Henry Wiggin & Company, Limited; H. & J. Beach, Limited; Barker & Allen, Limited; J. G. Beddoes & Company; Birmingham Metal & Munitions Co., Limited; W. Canning & Co.; Elkington & Company, Limited; Joseph Lucas, Limited; The Mint, Birmingham, Limited.

Newcastle: Newcastle & District Electric Lighting Company, Limited; Newcastle-on-Tyne Electric Supply Company, Limited.

Sheffield: Arthur Balfour & Company, Limited; Cammell Laird & Company, Limited; Daniel Doncaster & Sons, Limited; Thomas Firth & Sons, Limited; W. Jessop & Sons, Limited; Steel, Peech and Tozer, Limited; Walker and Hall, Limited.

Widnes: Broughton Copper Company; McKechnie Bros., Limited; United Alkali Company, Limited.

CUBA

Spanish-American Iron Company; Cuba Copper Co. (El Cobre); Juragua Iron Company.

AUSTRALIA

Tasmania: Mount Lyell Mining and Railway Company; Mount Bischoff Mine; Dundas Cuni Mining Company, Limited; Copper-Nickel Prospecting Syndicate.

New South Wales: North Broken Hill, Limited.

NEW CALEDONIA

La Société Anonyme le Nickel; Les Hauts-Fourneaux de Nouméa; The Nickel Corporation; Société Minière Caledonienne.

UNITED STATES

Baltimore, Md.: Maryland Steel Company.

New York: International Nickel Company (also Constable Hook, N.J.); Amalgamated Zinc Company; American Metal Company; New Jersey Zinc Company; The Dwight Lloyd Sintering Company, Inc.; General Chemical Company; A. Ledoux & Company.

Niagara Falls, N.Y.: Carborundum Company; International Acheson Graphite Company.

ONTARIO, CANADA

Porquis Junction. Alexo Mining Company.

Iroquois Falls: Abitibi Pulp & Paper Company, Limited.

South Porcupine: Dome Mines, Limited.

Timmins: Hollinger Consolidated Gold Mines, Limited.

Cobalt. Coniagas Mines, Limited, Nipissing Mining Company, Limited.

Coniston: The Mond Nickel Company (also Clydach, Wales, and London, England).

Copper Cliff: The Canadian Copper Company.

Murray Mine: British America Nickel Corporation, Limited (also Toronto).

Deloro. Deloro Smelting & Refining Company, Limited.

Niagara Falls: The Hydro-Electric Power Commission; Ontario Power Company.

St. Catharines: Coniagas Reduction Company, Limited.

Sulphide: Nichols Chemical Company, Limited.

Toronto: Hydro-Electric Power Commission of Ontario; Electrical Development Company, Limited; Moffat-Irving Steel Works, Limited; The Standard Chemical Iron and Lumber Company, Limited (also Longford); Toronto Power Company.

Welland: Metals Chemical Company, Limited.

Windsor: The Canadian Salt Company, Limited.

Individuals

NORWAY

Arendal: Mr. Emil Hallevig, British Vice-Consul.

Kristiania: Mr. Esmond Ovey, British Legation; Mr. C. L. Paus, Commerical Attache, British Legation; Mons. Mai De Garston, British Vice-Consul; Mons. A. Jolivet, French Legation; Regnwald Blakstad; Mr. Berentzen; Mr. T. E. Blichfeldt; Admiral Boresen, Kristianssands Nikkelraffineringsverk; Dr. S. Eyde; Mr. Karl von Krogh; Mons. Callon, Norske Nitrad A/S Eydehavn; Mr. V. N. Hybinette.

Kristianssands: Mr. Torgny F. Torell, Nickel Works of Kristianssands.

FRANCE

Paris: M. Maurice Carrier, Administrator-Director La Société Anonyme le Nickel.

AUSTRALIA

Melbourne: Mr. D. H. Ross, Canadian Trade Commissioner; Mr. A. S. Patterson, Representative in Australia of the Massey-Harris Co. of Toronto; Mr. Bowes Kelly, Director Mount Lyell Mining & Railway Co.; Mr. Geo. Weir, General Manager, North Broken Hill, Ltd.; Mr. D. H. Dureau, Messrs. Brown & Dureau; Mr. Colin Fraser, Collins House.

Sydney: Mr. Mark Browne, Representative of the Nickel Corporation of New Caledonia; Mr. J. E. Carne, Government Geologist.

Adelaide: Mr. L. Keith Ward, Government Geologist; Mr. R. Lockhart Jack, Asst. Government Geologist.

Queenstown. Mr. R. C. Sticht, General Manager, Mt. Lyell Mine; Mr. V. Sawyer, Asst. to the General Manager, Mt. Lyell Mine.

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Zeehan: Mr. H. A. Vaudeau; Mr. A. D. Sligo.

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Nouméa: Mr. H. C. Venables, His Majesty's Consul; Mr. A. Frey, Inspector-General La Société le Nickel; Messrs. Laroque and Rougy, Les Hauts Fourneaux de Nouméa; Messrs. Leleu and de Casteljau, Representatives of The International Nickel Company (the Nickel Corporation and La Société Minière Caledonienne), as well as other gentlemen in other parts of New Caledonia.

EGYPT

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GREAT BRITAIN

Swansea: Mr. A. F. Eden, Anglo-French Nickel Company, Limited; Mr. A. W. Gemmill, Anglo-French Nickel Company, Limited; Mr. F. L. Merry; Mr. J. H. Wells, English Crown Spelter Company.

Clydach: Dr. C. Langer, Mond Nickel Company, Limited.

Llansamlet: Mr. Marmion, Swansea Vale Zinc Company, Limited.

Birmingham: Mr. G. A. Boeddicker, Henry Wiggin & Co., Limited; Mr. E. R. Canning, W. Canning & Company; Prof. Thomas Turner, University of Birmingham.

London: Sir George Perley, High Commissioner for Canada; Mr. W. L. Griffith, Permanent Secretary, High Commissioner for Canada; Mr. R. Reid, Agent-General for Ontario; Mons. Jean Perier, The French Commercial Attaché; The Rt. Hon. Sir Alfred Mond, Bart., P.C., The Mond Nickel Company, Limited; Mr. E. J. Harding, Secy. Dominions Royal Commission, Colonial Office; Dr. Wyndham R. Dunstan, Director Imperial Institute; Sir James J. Dobbie, Government Laboratory; Sir Thomas H. Elliott, K.C.B., Royal Mint; Sir Thomas K. Rose, Royal Mint; Sir Edward Rigg, Royal Mint; Mr. C. T. Davis, Colonial Office; Dr. R. T. Glazebrook, C.B., National Physical Laboratory, Teddington; Dr. Walter Rosenhain, National Physical Laboratory, Teddington; Dr. E. G. Spilsbury; Mr. G. C. Brown, Anglo-French Nickel Company; Mr. W. H. Goodchild; Mr. H. N. G. Cobbe; Mr. A. G. Charleton; Mr. D. C. Griffith; Mr. R. H. Humphreys, Royal Societies Club; Mr. J. R. Dunn, British America Nickel Corporation, Limited (also Toronto); Mr. W. A. Carlyle, British America Nickel Corporation, Limited (also Toronto); Mr. J. Allen Howe, Geological Survey; Mr. G. C. Lloyd, Iron and Steel Institute; Mr. Robert Mond, Mond Nickel Company, Limited; Mr. Bedford McNeill, Mining Engineer; Mr. C. Williamson Milne; Mr. C. McDermid, Institution of Mining and Metallurgy; Mr. W. E. F. Powney, London County Council Laboratories; Mr. G. Shaw Scott, Iron and Steel Institute; Mr. B. M. Venables; Mr. W. G. Wagner, G. T. Holloway & Company, Limited; Mr. W. W. Ware, Home Office, Whitehall.

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UNITED STATES

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Baltimore, Md.: Dr. J. Singewald, Johns Hopkins University; Mr. F. W. Wood; Mr. F. A. Weymouth.

Humboldt, Ariz.: Mr. G. M. Colvocoresses, Consolidated Arizona Copper Co.

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Washington, D.C.: Mr. C. G. Gilbert, United States National Museum; Dr. W. F. Hildebrand, Bureau of Standards; Dr. Frank L. Hess, United States Geological Survey; Dr. G. Otis Smith, Director U. S. Geological Survey; Dr. F. E. Wright, Carnegie Geophysical Laboratory.

Oakland, Cal.: Mr. J. Mitchell, State Board of Equalization.

Denver, Colo.: Mr. J. B. Phillips, Chairman Colorado Tax Commission; Mr. C. P. Link, Colorado Tax Commission.

Lansing, Mich.: Mr. B. F. Bartless, Secretary State Tax Commission; Mr. R. C. Allen, State Geologist.

Minneapolis, Minn.: Mr. F. B. Snyder, Attorney-at-Law.

St. Paul, Minn.: Senator S. Lord, Chairman State Tax Commission; Mr. J. G. Armson, State Tax Commission; Mr. James T. Hale, State Tax Commission; Mr. Rukard Hurd, Engineer, State Tax Commission.

Carson City, Nev.: Mr. L. F. Adamson, Nevada Tax Commission.

Santa Fe, N.M.: Mr. A. E. James.

Oklahoma, Okla.: Mr. E. B. Howard, State Auditor.

Salt Lake City, Utah: Mr. H. Bennion, State Board of Equalization; Mr. W. Bailey, State Board of Equalization.

Madison, Wis.: Mr. Nils P. Haugen, Chairman State Tax Commission; Mr. Thomas E. Lyons, State Tax Commission; Mr. C. Atwood, State Tax Commission; Mr. W. O. Hotchkiss, State Geologist; Prof. T. S. Adams, late State Tax Commissioner, now of Yale University, New Haven, Conn.; Mr. C. K. Leith, Professor of Geology, University of Wisconsin.

CUBA

Santiago de Cuba: Mr. M. I. Quiros; Mr. D. B Whitaker.

El Cobre: Mr. E. B. Nagle.

Camagüey: Mr. Chas. L. Drake.

Felton: Mr. W. M. Shoop; Mr. A. H. Weaver

CANADA— ONTARIO

Belleville: Mr. J. W. Evans, Tivani Steel Company.

Cobalt. Mr. Arthur A. Cole, Mining Engineer, Timiskaming and Northern Ontario Railway Commission.

Coniston: The Mond Nickel Company, Ltd.; Mr. C. V. Corless, Manager, Mr. O. Hall, Mr. F. J. Eager, Mr. A. L. Sharpe, Mr. W. J. Mumford, Mr. V. P. Row; Mr. R. N. Palmer.

Copper Cliff. Canadian Copper Company; Mr. A. D. Miles, President, Mr. J. L. Agnew; Mr. J. C. Nichols, Mr. Charles Collins, Mr. W. J. Trestrail; Mr. Charles Miller; Mr. W. J. Hambly; Mr. A. F. Brock; Mr. J. Rogers; Mr. C. H. Hitchcock; Mr. E. T. Corkill.

Deloro: Mr. Thos. Southworth; Mr. S. B. Wright; Prof. S. F. Kirkpatrick, Deloro Smelting and Refining Company, Limited.

Kingston: Mr. M. B. Baker, Professor of Geology, Queen's University.

Murray Mine: Mr. E. Hibbert, British America Nickel Corporation, Limited.

Niagara Falls: Mr. J. H. Jackson, Supt. Queen Victoria Niagara Falls Park.

Ottawa: Mr. R. G. McConnell, Deputy Minister of Mines; Dr. Eugene Haanel, Director, Mines Branch; Mr. G. C. Mackenzie, Mines Branch; Mr. Albert L. Entwistle, The Mint.

St. Catharines: Lt.-Col. R. W. Leonard, Coniagas Reduction Company, Limited; Mr. Robert L. Peek.

Sudbury: Mr. Thomas Travers, Mayor; Mr. P. Gorman, President Board of Trade; Mr. H. M. Roberts, of the E. J. Longyear Company.

Sulphide: Mr. A. Dubois, Nicholls Chemical Company.

Timmins: Mr. P. A. Robbins, Manager, Hollinger Consolidated Gold Mines, Ltd.; Mr. A. R. Globe, Hollinger Consolidated Gold Mines, Ltd.; Mr. W. J. Wilson, Mayor.

Toronto: Dr. A. P. Coleman, Professor of Geology, University of Toronto; Mr. G. A. Guess, Professor of Metallurgy, University of Toronto; Mr. H. E. T. Haultain, Professor of Mining Engineering, University of Toronto; Mr. W. Lash Miller, Professor of Physical Chemistry, University of Toronto; Mr. H. G. Acres, Engineer, Hydro-Electric Commission; Mr. T. R. Jeffery, Engineer, Hydro-Electric Commission; Mr. C. W. Knight, Asst. Provincial Geologist; Mr. Alfred Burton, Secy. Society of Chemical Industry; Mr. E. P. Mathewson, British America Nickel Corporation, Limited; Mr. J. Watson Bain, Professor of Chemical Engineering, School of Practical Science; Mr. W. K. McNeill, Provincial Assayer; Mr. George R. Mickle, Mine Assessor, Bureau of Mines; Mr. A. Nieghorn, Nicholls Chemical Company, Limited; Mr. W. R. Rogers, Topographer, Bureau of Mines; Mr. T. F. Sutherland, Chief Inspector of Mines, Bureau of Mines; Mr. W. J. Bell, Cartographer, Bureau of Mines; Mr. P. A. Jackson, Surveyor, Bureau of Mines.

Welland: Mr. J. H. Charles, Metals Chemical Company, Limited.

Windsor: Mr. E. G. Henderson, Canada Salt Company, Limited.

Montreal, Que.: Prof. Alfred Stansfield, McGill University.

CHAPTER I

Agitation for Home Refining of Nickel

Importance of Sudbury Deposits

The large bodies of nickel-copper ore in the Sudbury district are, all things considered, the most important and valuable of the mineral deposits yet found in Ontario. Their working requires more labour than the mines of any other branch of the industry. Their number and dimensions are such as to predicate a long life for the nickel business, and to fully warrant the large investments of capital which have been and are still being made for their equipment and operation. The profits realized by nickel mining companies of late years have been large, and were never larger than at the present moment.

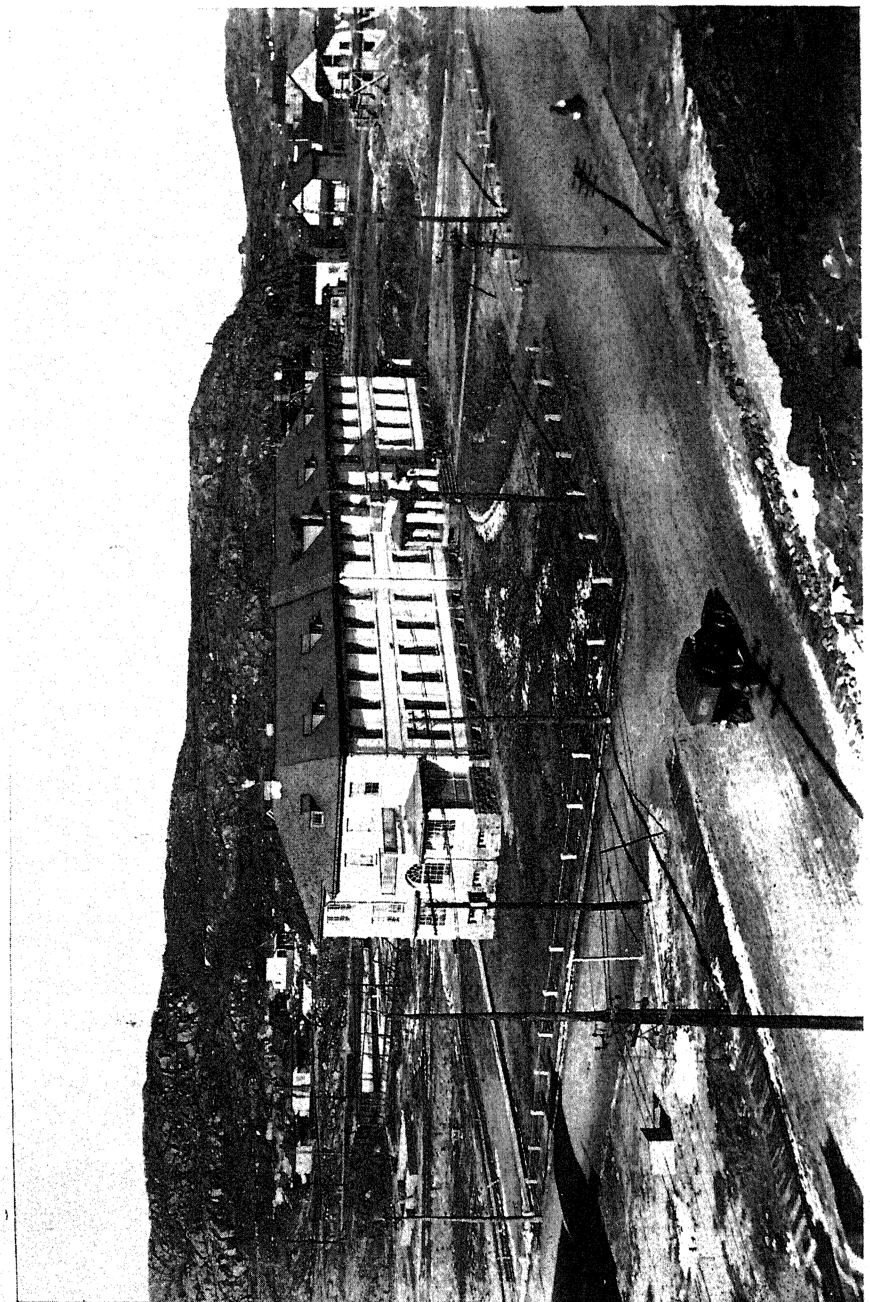
A considerable portion of the population of the Sudbury district is directly, and a large portion indirectly, dependent upon the mining and treatment of the nickel-copper ores for its maintenance and retention on the ground. Lumbering is an important business, but it must be admitted that in the Sudbury region it is a disappearing business, for lumbering methods as practised in Canada, have in the past mainly concerned themselves with only one crop of trees, namely the first.

It would be wrong to belittle the agricultural resources of the district. In the central plain, enclosed by the nickel-bearing band of ancient rocks, there is a tract of good and well cultivated land, the products of which find a ready and insatiable market in the mines and mining towns and villages. But no one acquainted with the area, extending say from Lake Wanapitei to Windy lake, or from the Mond smelting works at Coniston to the High falls of the Spanish river, will claim for it a fertile soil or general suitability for farming purposes. The surface is, in the main, rough and rocky, and there are many swamps. In the valleys between hills of granite or gneiss or greenstone, or in the "flats" bordering the rivers and streams, good crops of hay, oats and potatoes can be grown. In short, the district is neither better nor worse, from the farmer's point of view, than the territory of which it forms a part—the hard and rugged pre-Cambrian area, stretching along the north shore of Lake Huron, from which in the geologic past, the glaciers swept and ground the surface rocks and deposited them as gravel, sand and clay in the southern parts of the Province.

But the importance and significance of these ore bodies are not confined to the district in which they are situated. Ever since it became known that a small proportion of nickel added to steel greatly enhanced its strength and lessened its tendency to corrosion, it has become increasingly clear that in these nickel deposits Ontario possesses an element which can and ought to be made to contribute materially to her industrial progress.

Discovery of Nickel-Steel and its Effects

After the results of James Riley's classic experiments were announced in 1889 on the nickel-steel alloys made by Marbeau in France, corroborated as they were



Hospital of the Canadian Copper Company, Copper Cliff, Ontario. Photograph taken Nov. 21st, 1916.

by the work of Hall, Gamgee and many other observers, it speedily became established that nickel was essential for the manufacture of high-class steel. So extensive a field of usefulness was thus opened up that nickel, previously employed in the arts on a very small scale, came by degrees into large demand which, especially of recent years, has gone on at an accelerating rate.

The chief sources from which the small amount of nickel required had been supplied, were New Caledonia, Norway, Sweden, Germany and the United States. In all of these places, except the first, the deposits were small and apparently incapable of extended production, save perhaps in Norway.

In the island of New Caledonia, situated in the South Pacific ocean, and for many years used by the French as a convict colony, nickel deposits were discovered in 1874, and began to be worked in 1875.

In the early stages of the industry New Caledonia was able to maintain her lead in meeting the growing demand, and in fact her mines increased their output more rapidly than did those of Ontario. Thus in 1893 New Caledonia produced 3,180 tons of metallic nickel, Ontario, 1,653; in 1897 the New Caledonian output was 3,458 tons, that of Ontario 1,999. Five years later, in 1902, the figures were 7,045 tons and 5,945 tons, respectively. In 1903, for the first time, Ontario took the lead with 6,998 tons, as against 4,177 tons for New Caledonia. The latter regained her place in 1904 with 5,327 tons, compared with 4,729 for Ontario, but in the following year, 1905, the Ontario output rose to 9,503 tons, while that of New Caledonia reached 6,765 tons only, and the superiority thus established has since been retained. Indeed, as the statistics show, although the industry in New Caledonia is still vigorous, the gap between its production and that of Ontario has been widening year by year.

Why Not Refine in Ontario ?

One of the early uses for which nickel-steel was found to be adapted was the manufacture of armour-plate for war vessels. France was early in the field in experimenting with nickel-steel armour-plate. Trials carried out in 1890 and 1891 by the Navy Department at Washington showed that with a covering of the new armour a battleship was well nigh invulnerable compared with vessels clad with the armour previously in use. The supremacy of the British fleet is synonymous with the maintenance of the British Empire, and popular feeling in Ontario was not long in drawing inferences and conclusions. If nickel-steel armour was the best, of course the British fleet would adopt it. After a somewhat prolonged trial, it did so Popular feeling was gratified by the fact that the element which contributed so strongly to Britain's naval superiority was produced from Ontario mines, although as a matter of fact, New Caledonia nickel only was used in British armour-plate until 1904. It was known that the ore was mined and smelted in this Province, but that the refining took place mainly in the United States, and popular feeling began to ask "Why is nickel not refined in Ontario?"

It may not be possible to enumerate all the elements of this insistent and persistent inquiry, but analysis will reveal at least some of them. There is, first, the natural desire to have all the work on raw material which is produced here done at home, up to the point of turning out the finished article. Employment

is given to Canadian workmen, Canadian chemists and Canadian experts. The rewards of this labour are spent in Canada and swell the volume of Canadian business. There is a feeling of impatience at seeing Canadians hewers of wood and drawers of water, while in another country, technical and skilled work is performed in refining an article of Canadian origin. It is felt that Canadian prestige would be enhanced by the establishment of an important industry of the kind, which would "build up Ontario." For some time after smelting began at Sudbury, low grade or "standard" matte only was made, containing say 40 per cent, of nickel and copper combined, and when the production of high grade or Bessemer matte, containing about 80 per cent. of the metals became the established practice, it was considered that a decided step in advance had been taken. But even Bessemer matte failed to silence the query "Why cannot nickel be refined at home?"

War Reveals Real Reason for Inquiry

The outbreak of the great war made clear the most deeply seated and most potent of the feelings which underlay the inquiry. Nickel was a necessity in modern warfare; it was needed for armour-plate, for rifle-barrels, for heavy ordnance, bullet coverings, cartridge cases, automobile parts, and the whole catalogue of military and naval equipment. Not an ounce should go to the enemy! Every pound of Canadian nickel must be placed at the service of the Mother country and her Allies! Yet how to ensure this while the metal is refined in a foreign country, by a foreign company, with the countless opportunities of its passing into the hands of Germans or German sympathizers?

It is true that arrangements satisfactory to the British and Canadian governments were made to meet this situation almost immediately after war was declared: but a certain amount of uneasiness has remained, fed by newspaper articles and editorials, which was aggravated by the arrival at Baltimore in July last of the German submarine "Deutschland," bringing a cargo of dye stuffs and advertising its intention of returning with a cargo of nickel, and also by a subsequent repetition of the feat, in November. It is the fact of the British Empire being at war, and at war with a shameless and ferocious enemy, that gives special point to the desire to have our nickel refined at home. The plan adopted to ensure that no Canadian nickel shall find its way into German hands during the war was beyond doubt well calculated to accomplish that end; but it is asked, who can say that should another world-struggle involve our country or our Empire, a like happy condition will recur? Suppose the United States were to decide she needed for her own use the nickel now being refined there from Canadian ore. Canada might indeed restrain the exportation of matte, but this would not put her in possession of the refined nickel, were there no refineries here. The result might well be a shortage of nickel while the need was at its height, and a shortage of nickel might be a weakness sufficient to determine the issue of a war.

Governmental Efforts to Establish Home Refining

It is not surprising that it has been an object of governmental endeavour to establish the business of nickel refining in this country from the time the mining of the ore began in Ontario. The question has been in no sense a party one. Every Provincial administration and every Legislative Assembly for the past

twenty-five years has given time and attention to it. Nor has the discussion been confined to the Provincial arena. The Parliament of Canada has time and again discussed the question, and as long as nineteen years ago placed in the hands of the Governor-in-Council power to impose a duty of ten cents a pound on the nickel and two cents a pound on the copper contents of matte exported from Canada—a power which has never been exercised. It will not be out of place to record here, in a summary way, the exertions put forward by governments and Parliaments and their officials to give effect to the popular feeling.

At the very outset, and even before the ores of Sudbury were known to contain nickel, a committee of the House of Commons, in the year 1886, took action to ensure that the ores should be refined in Canada. The committee refused to report a bill authorizing the Canadian Copper Company—an Ohio corporation—to carry on operations in this country until its promoters promised to establish their refinery works here, and agreed to have the bill amended accordingly. Unfortunately, the amendment as drawn was permissive only, not compulsory, and it failed of effect. The story is more fully told at page 62.

Sir Charles Tupper and Mr. S. J. Ritchie

Another early effort arose out of the search for a market for the products of the Sudbury mines, which naturally exercised the minds of their owners after the ores were found to contain nickel. The first president of the Canadian Copper Company, Samuel J. Ritchie, of Akron, Ohio, was not slow in recognizing the significance of the discovery that the mines of Sudbury were, in reality, nickel rather than copper mines. Nickel steel had already been used in France for the making of armour-plate for war vessels. It contained 5 per cent. of nickel, and showed a tensile strain of 90 tons with an elongation of 8 per cent. Not being averse to combining business with patriotism, Mr. Ritchie thought it would be a good thing for the United States, as well as for the Canadian Copper Company, to clothe American battleships with nickel steel. Armed with the results of Riley's experiments, he interviewed Gen. B. F. Tracy, Secretary of the Navy at Washington, and succeeded in having that gentleman institute an inquiry into the merits of the new material. Mr. Ritchie also brought the Ontario deposits to the attention of Sir John A. Macdonald, Premier of the Dominion of Canada. The former being about to visit England and the continent of Europe to push Ontario nickel, Sir John requested Sir Charles Tupper, then High Commissioner for Canada at London, to accompany Mr. Ritchie in his travels, and especially to give him every assistance with the British Government, since the Sudbury deposits were "the largest in the world," and the extended use of the metal would obviously be a great advantage to Canada.

Accordingly, in the autumn of 1889, Sir Charles and Mr. Ritchie, along with Lieut. B. H. Buckingham, of the United States navy, representing his government, visited a number of the leading steel and ordnance makers in Britain and Europe, as well as the principal companies engaged in the production and refining of nickel. Among these were: Société le Nickel, which brought New Caledonian nickel ore and matte to France, Britain and Germany, and there refined it; the Krupp gun and steel works at Essen; the Steel Company of Scotland, Glasgow; Sir

Hussey Vivian's smelting establishment at Swansea; Henry Wiggin and Company, at Birmingham, nickel refiners; the crucible steel works of William Jessop and Company at Sheffield, and also the Rio Tinto copper mines in Spain. They found all these companies very much alive to the importance of nickel, especially in its use for nickel steel, and also greatly interested in learning about the new source of the metal opened up at Sudbury. Several of the company presidents or managers expressed a desire to become associated with the ore deposits, or offered to contract for the purchase of the Canadian Copper Company's output of matte.

Sir Charles' Report

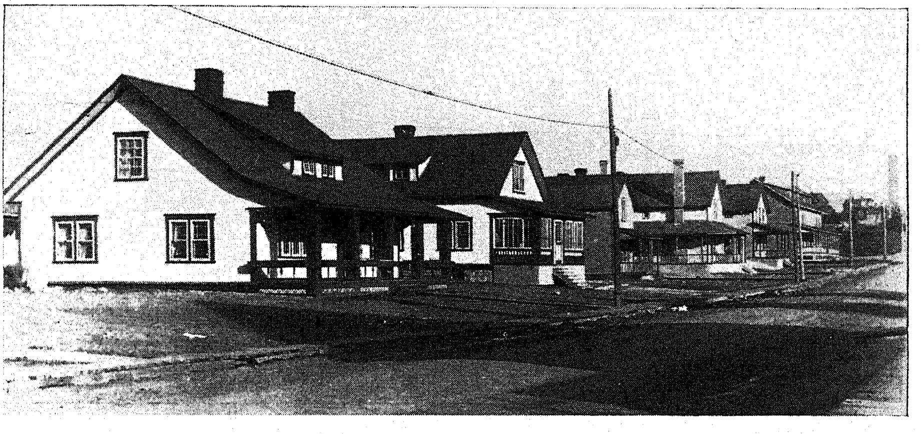
The High Commissioner, in making his report to the Canadian Government in November, 1889, emphasized the value of nickel in producing the new alloy steel which the experts with whom he had conversed were certain would work a revolution in the manufacture of guns and armour-plate. He pointed out that there was at the time a dearth of nickel to such an extent that the development of the nickel steel industry was being hindered, the Jessop firm in Sheffield having orders for thousands of tons which they could not supply for want of nickel. As regards the special interest of Canada, which owned "the governing supply of the world," Sir Charles Tupper pertinently asked: "Why cannot Canada herself make this steel?" Aid from British capitalists and steelmakers would be forthcoming, and Sir Charles saw no reason why, in Hastings county for instance, a smelting industry could not be established where the iron ores of that district might be reduced and combined with the nickel of Sudbury to make ferro-nickel. Nay, he asked: "Why should Canada not go further and make the nickel-steel and armour-plate on her own territory?" He concludes thus:

> If the Government takes the proper action, there is no doubt that the best skill and the strongest financial backing in England could be had to carry it on, and it really looks as if it were possible for Canada to control the character and efficiency of the guns and navies of the world. I am glad to say this much from the statements of every expert with whom I have talked. . . . I cannot but feel that it is Canada's golden opportunity to move and produce her own iron and steel as well as nickel-steel for other countries.

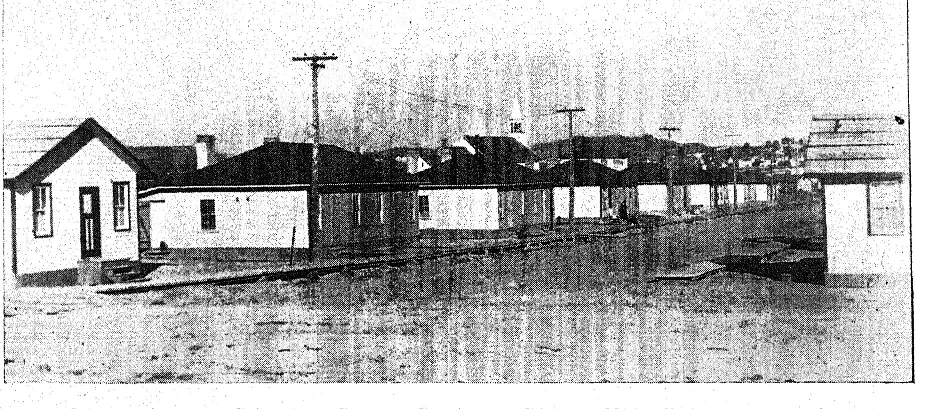
It is possible that Sir Charles Tupper may have been looking through Mr. Ritchie's spectacles when he wrote this report. That gentleman's company owned iron lands in Hastings as well as nickel mines at Sudbury, and to bring the two metals together to form the basis for a large business enterprise, was at that time one of Mr. Ritchie's ambitions. It turned out that the ores of Hastings were unsuitable for the purpose, and his hopes in this particular were never realized. Events, however, have shown that both Sir Charles Tupper and Mr. Ritchie were correct in judging that the discovery of the nickel deposits of Sudbury was an event of first-class importance in the industrial history of Canada. Sir Charles did not indicate the nature of the "proper action" which he suggested that the Canadian government might take, and it does not appear that it took any; but it may be that the offer made by the government of Ontario spoken of below owed its origin to the European visit of S. J. Ritchie and Sir Charles Tupper.

That visit, at any rate, bore fruit across the border. After receiving the report of the United States' representative, Lieut. Buckingham, Gen. Tracy lost no time in testing whether the French Government was on the right track in

Officials' houses, Canadian Copper Company, Copper Cliff, Sudbury area, Ontario.



Club houses, Canadian Copper Company, Copper Cliff, Sudbury area, Ontario.



Workmen's houses, Canadian Copper Company, Copper Cliff, Sudbury area, Ontario.

introducing nickel steel armour into its navy. He ordered a nickel steel plate from the Creusot works in France, also a plain steel plate from the same works, and one from Cammell and Company of Sheffield. These he subjected to a trial at the government proving-grounds at Annapolis, in September, 1891. The plates were fired at by eight-inch guns, at short range, and the superiority of the nickel steel plate over both plain plates was overwhelmingly established. Gen. Tracy at once requested Congress to appropriate one million dollars for the purchase of Sudbury matte, to be used in making nickel steel and armour-plate for the United States navy, and Congress complied with the request. Further trials in France and Germany and also in the United States, confirmed the results already obtained, particularly when the nickel steel armour had been subjected to a process of face-hardening by one or other of several approved methods. United States, Germany, France and Russia adopted nickel steel plate for the vessels of their navies. The British Admiralty were more conservative, but eventually did the same, and nickel steel armour is now recognized as the best possible protection for battleships by all the navies of the world.

Offer of Ontario Government in 1891

In 1891 an earnest effort was made by the Ontario government to interest the government of Great Britain in a joint undertaking which would have for its object the establishment of nickel refineries and nickel steel works in Ontario, with the view of ensuring an ample supply of nickel for British military and naval use, and at the same time of developing the manufacture of nickel and iron in this Province. Sir Oliver Mowat, then Premier, and Hon. A. S. Hardy, Commissioner of Crown Lands, placed the matter in a despatch before the Imperial authorities. After rehearsing the great nickel resources of Ontario, and the importance which the metal a short time before had, by Riley's experiments and those of the United States Navy Department, been conclusively shown to possess, especially for armour-plate, the despatch goes on to say:

In view, therefore, of the important national uses to which nickel is being applied by foreign governments, and of the consequent demand for mining locations here, it has occurred to the undersigned that an arrangement might be made under which the government of the United Kingdom should acquire a substantial, possibly a controlling, interest in the nickel deposits of this Province.

In anticipation of making this offer, and also to permit of the adoption of a new mineral law better suited to the circumstances, all the nickel-bearing lands in the Province had been withdrawn from sale in December, 1890, and the government was therefore in a position to recommend the undertaking to the Legislature should the Imperial authorities concur. The area within which nickel had been found was represented as being very large, and although considerable land had been sold for mining purposes, no doubt was entertained of the existence of rich and extensive ore ranges in much of the unsold territory yet in possession of the Crown. Nor were the possibilities of obtaining revenue for the Provincial chest overlooked.

Should the Imperial Government be inclined to enter upon a proposition for negotiations, evidence may be furnished of the existence of nickel-bearing ore in economic quantities throughout the district referred to, from scientific surveys and the reports of explorers, with a view of entering into arrangements (with the assent of the Legislature) for granting to

the Imperial Government, conjointly with the Province, or in such other manner as may be agreed upon, control over part or all of the nickel ore in the Crown lands of the district, subject to such arrangements for the establishment in Ontario of nickel-steel works or manufactures, the development of the mines and considerations of royalty on the ore, as may be mutually agreed upon and as shall be approved by the Legislature.

The iron mining industry of Ontario which was then (and still is) in a languishing condition, would also be benefitted, for the production of nickel steel was one of the primary features of the proposal.

It is part of the scheme of the government that the iron ores of the Province, of which there are large deposits within easy reach of railway transportation, should be utilized with the nickel ore in the production of nickel-steel; and for this purpose a sufficient quantity of iron lands belonging to the Province could be set apart and held by the two Governments, subject to the same arrangements as might be agreed to respecting the nickel lands, and with a like provision for payment to the Province of royalty upon the ore.

Patriotic attachment to the British Empire, as well as a desire to promote the welfare of the Province of Ontario, moved Sir Oliver and his colleagues in making the offer.

As a colony of Great Britain and as a part of the British Empire, our Province is concerned in all things which contribute to the greatness and stability of the parent State, and recognizing especially how much depends upon the maintenance of her historic position as a naval power, it would be agreeable to our people that the Legislature should further in any way consistent with its obligations to the Province, and the people of the Province, the means whereby that position may be more effectively safeguarded and preserved.

The proposition, on being received at the Colonial Office, was referred to the Lords Commissioners of the Admiralty for consideration. The Lords of the Admiralty did not take long to make up their minds. The suggestion did not commend itself to them, and while appreciating the courtesy and consideration that prompted the offer, they reported that they did not anticipate any difficulty in obtaining sufficient nickel for the requirements of Her Majesty's service through the ordinary channels. They concluded by expressing the hope that the government of Ontario would, for some long period to come, retain under its control some of the lands in which the nickel ore deposits were to be found.

Could the Offer Have Been Implemented?

It will be observed that the offer of Ontario was to convey to Great Britain "a substantial, possibly a controlling interest in the nickel mines of the Province," or in the alternative to enter upon an arrangement by which the authorities of Britain and those of Ontario might exercise a joint control, with the object of establishing the refining of nickel and the manufacture of nickel steel.

In 1891 the nickel-bearing areas had not been so carefully delimited and were not so well known as they are now. Ore bodies had been found over territory whose dimensions were given in the despatch as seventy miles in length by fifty in breadth, "containing nearly two and one-half million acres." The relations of these bodies to the rocks surrounding them had not then been worked out. It was apparently surmised that nickel might be found at any place over this extensive area, and that probably many rich deposits still remained undiscovered in the rough forested country of which the tract was composed.

Closer examination by prospectors and geologists since 1891 has given a clearer view of the actual mineral-bearing belt or belts, and it is now recognized

that instead of occupying a widespread tract, the nickel deposits are associated with a comparatively narrow band or bands of an intrusive rock called norite, which forms the rim of an ellipse about 36 miles long and 17 miles wide. Some prospectors prefer to speak of the southern or main, northern, eastern and western ranges, for the continuity of the elliptical belt is broken in a number of places, or at least is obscured by areas of drift. The investigations and studies of Coleman. Barlow and others have reduced the gross area favourable for the occurrence of nickel ores to much smaller dimensions than those which the state of knowledge in 1891 seemed to justify. As a matter of fact, most of the large and productive deposits of nickel-copper ores which have in the past, or are now, being worked. had already been discovered and had been granted by the Crown before the offer to the British government was made. The considerable deposits found since 1891 on lands then held by the Crown are few in number. They include the Whistle, an important deposit; the Kirkwood, a useful mine, though not among the largest; the Gertrude and the North Star, which have been less productive; also a number of the deposits on the eastern and northern ranges whose actual size has not yet been determined. During the present year (1916) the diamond drill has revealed the presence of a considerable quantity of nickel ore where the norite contact is covered with more than 100 feet of drift between the Garson mine and the known outcrops in Falconbridge township.

It can therefore be seen that the offer of the Ontario cabinet in 1891, although undoubtedly made in good faith, to give the Imperial government a "controlling" interest in the nickel deposits of Ontario, was one which it would have been difficult to carry into effect, if the offer included only the nickel properties then remaining in the possession of the Crown There was, of course, and yet is, the possibility of ore bodies being still undiscovered. Such there may be—probably are—hidden by lakes, swamps or overlying soil, like those newly found in Falconbridge, but the norite bands of the Sudbury region have for years been subjected to the keen-eyed scrutiny of intelligent and experienced prospectors, and it cannot be said that the probabilities are in favour of many such deposits being located. Nevertheless, the action of the Ontario government was a notable one, and argued an insight into the future which may be described as remarkable. Had the offer been met with an equal degree of imagination on the part of Great Britain, it is not easy to say what the results would have been. Even with the deposits found since 1891 a good deal of nickel could have been obtained, and it would always have been possible to purchase privately owned properties.

The proposals of the Ontario government having fallen through, the Order-in-Council withdrawing the nickel lands from disposal was rescinded in June, 1891.

Royalties on Nickel and Copper

The records of the Department of Lands, Forests and Mines (formerly called the Department of Crown Lands) show that as soon as the speculative public learned that nickel was a valuable metal, a rush to obtain nickel-bearing lands set in. Certain localities, like the township of Denison, were regarded with special favour. Practically every lot in this township was acquired from the Crown, gold as well as nickel having been found here. It may be well to explain the regulations

then in force governing the disposal of Crown lands for mining purposes. They were extremely simple. They did not require proof, or even assertion, that a discovery of mineral had been made, or that the lands were valuable for mineral. All that was necessary was to show by the affidavit of two "credible and disinterested" persons that the land was unoccupied, and that no adverse claim was asserted by anyone else, and payment having been made for the land, patent followed by title in fee simple. There was no obligation to work the deposit, and the owner was at liberty to allow his land to remain in a state of nature, if he chose to do so. The price of Crown lands was for a long time $1 per acre; in 1886 it was raised to $2 per acre. The excitement over nickel lands rose to a great height in the year 1890, and many speculators based their hopes for a fortune on the chance of their lands in Denison, McKim or Snider proving to contain a rich body of nickel-copper ore.

At the instance of the government, the Legislature amended the mining laws during the session of 1891, but the amendments were directed more towards obtaining a larger revenue from mining lands, by way of royalty and an increased purchase price, than to secure the refining of nickel or other ores in the Province. The latter object, it had no doubt been hoped, might be achieved if the Imperial authorities should decide to entertain the proposal submitted to them in April and under consideration while the Legislature was still sitting, but the session closed early in May, and the reply from the Home government, which put an end to its hopes, was not received until more than a month after prorogation. The proposed royalty on nickel and copper ore was 3 per cent. on the value at the pit's mouth. This was lowered in 1892 by allowing the cost of labour and explosives in mining and raising the ore to be deducted from the value of the same. In 1894 the rate was reduced to 2 per cent., and was abolished altogether in 1900. The royalty provisions never brought in a dollar of revenue, and were unpopular from the beginning, largely because they applied to future grants only, and not to lands already patented, thus being discriminatory in their effect.

Dominion Imposes Export Tax

The feeling that Canadian nickel should be refined in Canada was never long dormant, and next found formal expression in the Parliament of Canada. In 1897 the tariff policy of the United States, naturally at all times a matter of interest in this country, was pressing upon the Canadian lumbering industry by reason of an import tax on sawn lumber. As a counter-measure, the Canadian government proposed an export duty on logs and pulpwood to restore the equilibrium of tariff taxation between the unmanufactured logs and the sawn product, and thus favour the manufacture of the raw material in Canada. The occasion was deemed opportune to connect with this proposal a similar one respecting the ores of certain metals, namely, nickel, copper, lead and silver. As regards nickel and copper, Parliament enacted that "on nickel contained in matte or in the ore, or in any crude or partially manufactured state, and upon copper contained in any matte or ore which also contained nickel" when exported from Canada "an export duty should be levied not exceeding ten cents per pound on nickel and two cents per pound on copper."

These provisions were not to come into effect until proclaimed by the Governor-in-Council. This left it optional with the government to make the enactment effective, and the necessary proclamation has never been published. As the United States continues to admit nickel matte and nickel ore free of duty, and maintains an impost of 10 per cent., ad valorem on refined nickel, it is evident that the tariff arrangements of that country, which furnishes the largest market for Canadian nickel, are unfavourable, and beyond doubt designedly so, for the development of the nickel refining industry in Canada.

The object aimed at by providing for export duties on unmanufactured sawlogs and pulpwood was, as has been stated, to induce the manufacture of these raw materials in Canada itself. This was a matter of considerable moment to Ontario, since large rafts of logs were year by year being towed from the north shore of Lake Huron across that lake to be sawed in the mills of Michigan, and smaller quantities were rafted from the west shore of Lake Superior to mills at Duluth. The exports of pine sawlogs amounted to many millions of feet board measure. In 1893, 236,000,000 feet board measure were exported; in 1896, 248,000,000; and in 1898, the last year of exportation, 236,000,000 feet.

The Manufacturing Condition for Sawlogs

The threat of an export duty on logs rafted to the States was met by a provision adopted by Congress for doubling the import tax on sawn lumber from any country imposing an export tax on logs. The government of Ontario, however, solved the situation and saved the sawmilling business to the Province. An Order-in-Council was passed, dated 17th December, 1897, providing that all pine timber cut on Crown lands should be manufactured into sawn lumber in Canada. The logs exported were, for the most part, cut on Crown lands under authority of timber licenses issued annually by the government. This was confirmed by a statute at the following session of the Legislature (61 Vict., Chap. 9), and when the timber licenses came to be renewed on the 1st of May, 1898, the "manufacturing condition," as it was called, was found to be contained in all of them. Suit was brought to test the validity of the legislation, but the courts held it to be good. Mills and machinery were transferred from Michigan to the north shore of Lake Huron, where villages and towns grew up devoted to the sawmilling and wood-working industries.

It has been argued, and with some speciousness, that similar action regarding nickel would bring about similar and equally satisfactory results. The cases, however, are fundamentally different. The pine trees grew on soil belonging to the Crown, and only the right to cut and remove them was disposed of. This was done, not by a grant outright, but by licenses issued for a year only, and it was within the power of the government to insert in the licenses when renewing them such conditions respecting the cutting of timber as might from time to time seem desirable. Nickel ore, on the other hand, is extracted from land the fee simple of which has been sold and granted by the Crown. No requirement of refining the ore within the country formed part of the original bargain and sale. It was not open, therefore, for the Government to provide by Order-in-Council, that as a condition of the use of their lands, the owners should be obliged to treat their ores up to the point of refinement within the boundaries of Canada.

Ontario Government Authorizes Second Offer

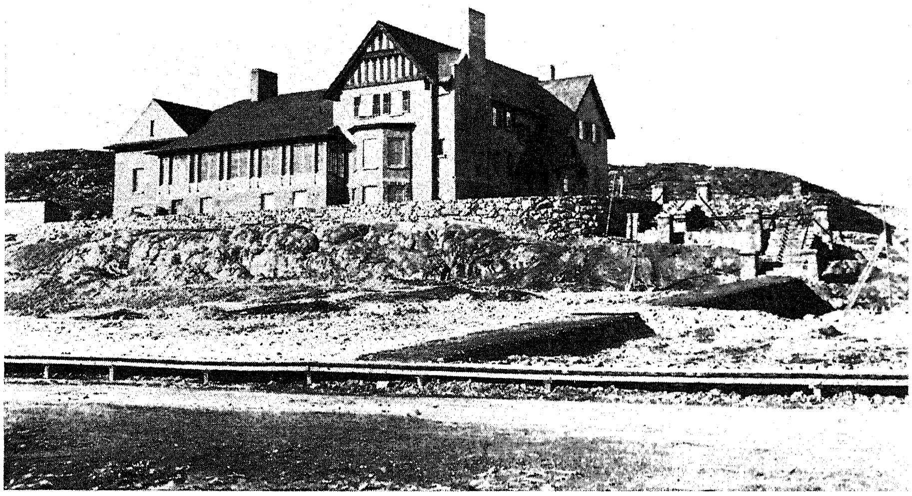
But the question of refining nickel at home would not down. The Spanish-American war of 1898 had demonstrated the excellent qualities of the nickel steel armour-plate carried by the United States battleships, and the "just and reasonable claim" for "the largest possible employment of capital and labour in the country which supplied the raw material" for refined nickel, was brought to the attention of the Provincial Government by the then head of the Bureau of Mines, Mr. Archibald Blue, who recommended (1) A renewal of the negotiations with the British government, in the hope of inducing them to enter the field of nickel refining in Ontario, for the supply of Imperial requirements; (2) A request to the government of Canada to impose the export duties authorized by Parliament on nickel-copper matte exported from the country; (3) A clause in all future grants of land that nickel and copper ores found thereon should be refined in the Province, upon penalty of forfeiture of the grant. The government approved these suggestions, and an Order-in-Council embodying them was passed 24th November, 1899.

It does not appear that any communication was ever addressed, either directly or through Ottawa, to the authorities in Downing street inviting them to reconsider their decision of 1891, nor can it be found that the powers at Ottawa were ever formally invited to levy the export duties. The form of land patent was changed so as to bind future grantees of nickel-copper lands to refine the ores in the Dominion of Canada, and for a time all grants of mineral land were issued subject to this condition. By the Act to Amend the Mines Act, 63 Victoria, chapter 13, section 3, this provision was rescinded, and the requirement was annulled as regards all grants already made.

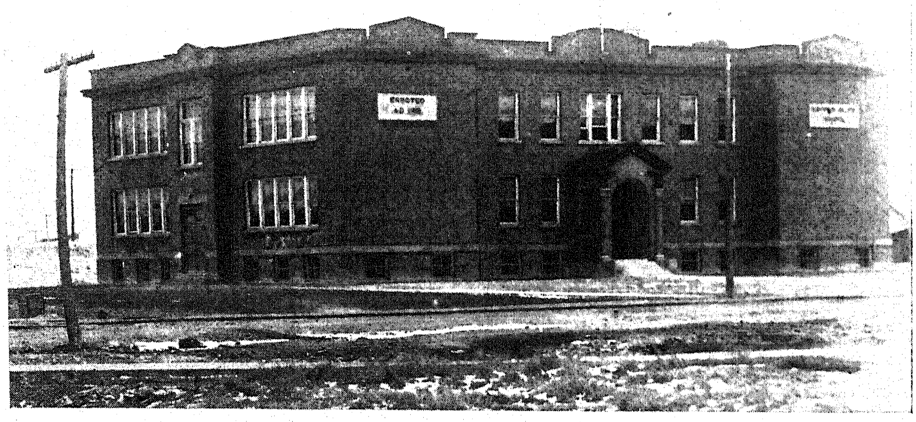
Provincial Legislature Tries Licensing System

The last-mentioned Act, passed in 1900, exhibits the first attempt by the Legislature to set up machinery which would operate to provide revenue, and at the same time exercise pressure on mining companies to refine their nickel and copper ores in the Province. To some extent its provisions were modelled on those which regulated the cutting of timber on Crown lands. No one, it was enacted, should carry on the business of mining except under authority of a yearly license issued by the Department of Lands, Forests and Mines; the fee for such a license should be based on the gross quantities of the ores or minerals raised by him during the preceding year, computed for ores of nickel at $10 per ton, or $60 per ton if partly treated or reduced, and for ores of copper and nickel combined at $7 per ton, or $50 per ton if partly treated or reduced. The license fees were to form a charge on the mine which should have priority over all other charges thereon, and non-payment was declared ground for forfeiture of the lands. To offset these provisions, where ores were treated in Canada so as to yield fine metal, the fees, or a proportion of them, were to be remitted. The Act was not to take effect until proclaimed by the Lieutenant Governor-in-Council.

Some of the nickel mining companies petitioned the government of Canada to disallow this Act, partly on the ground that it interfered with the right of that government to regulate matters of trade and commerce, and partly because, as they alleged, its provisions practically amounted to confiscation of their properties.



Club house, built by the Canadian Copper Company at Copper Cliff, Sudbury area, Ontario. Photograph taken Nov. 21st, 1916.



Copper Cliff School, Copper Cliff, Sudbury area, Ontario.

The Minister of Justice, Hon. David Mills, impressed by these representations, communicated his objections to the government of Ontario. The Attorney-General for the Province, Hon. J. M. Gibson, defended the legislation, and it was eventually agreed (May, 1901) between the two governments, that the constitutionality of the Act should be referred to the Supreme Court. No reference was ever made. Owing to the Act not having been proclaimed by the Lieutenant Governor-in-Council it remained a dead letter, and was repealed by the Mines Act, 1906.

Imperial Government Shows Interest

This is an appropriate place in which to summarize some interesting correspondence which passed between the governments of Great Britain and Canada in 1904, and which throws not a little light upon the importance placed upon nickel for naval and military purposes by the British Admiralty. Mr. T. M. Kirkwood, a citizen of Toronto, offered for sale certain nickel deposits in the Sudbury district to the British Government at a price of $450,000, describing them as being three miles from the Canadian Pacific Railway, and showing 1,200 feet of solid ore on the surface, etc. In a postscript to his letter Mr. Kirkwood added that the Americans were buying up nickel lands in Ontario, and that if he did not succeed in disposing of these properties in England, they would soon own these also, which were "the only undeveloped properties on the market." Mr. Kirkwood, who went to London for the express purpose, had the assistance of Sir Charles Tupper as High Commissioner, in laying the proposal before the Imperial government. The properties in question were the "Big Levack" and "Levack" mines. The Lords Commissioners of the Admiralty declined the offer, declaring themselves satisfied that no necessity existed for incurring a large outlay in the acquisition of nickel properties. The mines named are now owned by the Mond Nickel Company, and the Levack is one of the chief sources of that company's present ore supply.

Mr. Kirkwood's postscript, however, was not lost on their Lordships of the Admiralty. They deemed it advisable to make inquiries regarding the nickel situation in Canada, and did so through the ordinary channels of communication. Going back to the offer of the Ontario government in 1891, they referred to the hope they had then expressed, that notwithstanding the proposals for a joint undertaking to develop the nickel industry in Ontario had not been accepted, the Provincial government would for some period retain under its control some of the nickel-bearing land. Outlining their practice as to nickel, they stated that the armour-plate manufacturers of England were required to maintain in that country large stocks of nickel for a number of years ahead, the existence of which was the subject of periodical verification by Admiralty officers. Their Lordships added that they were taking steps to ascertain the suitability of the nickel produced in Canada for the manufacture of armour-plate, etc., for His Majesty's navy, with the view of its utilization for this purpose, if found in all respects suitable. They deemed it probable that even in war time, there would be no insuperable difficulty in obtaining supplies of ore from Canada if necessary, and were satisfied that the position was already sufficiently safeguarded. Nevertheless, in view of the possibility pointed out by Mr. Kirkwood that foreign companies might acquire further nickel-bearing

areas in Canada, their Lordships inquired whether the government could not retain rights over a considerable extent of ore-bearing land, or rights of pre-emption over the output, so as to secure adequate supplies in case of necessity for Imperial purposes. The Colonial Secretary supplemented this suggestion by asking whether it could not be provided in future grants of nickel-bearing lands, that any company working the same should be British and should not pass under foreign control.

The Ontario Government's Reply

The reply of the Ontario government, to whom the correspondence was referred, expressed doubt as to the feasibility of the British proposals. With respect to retaining unalienated nickel lands under its control, the difficulty was to say in advance of exploration and discovery, whether any particular tract contained nickel deposits. The law declared the public lands to be open for prospecting, and when a discovery was made, the discoverer naturally perfected his title in the manner prescribed by law. If lands were withdrawn from exploration, prospectors would have no inducement to examine them, and no discovery would be made. All known deposits had already passed into the hands of private owners. Whereas in 1891, a former administration had offered to convey to the British Government "a substantial, possibly a controlling interest" in the nickel deposits of the Province, it was now questionable whether, even at that early date, the promise could have been made good. The suggestion as to retaining or acquiring rights of pre-emption over the nickel output invited action by the government of the Dominion, not of the Province. Finally, as to the proposal that in future nickel lands should be granted only on condition that any company working them should be and remain British, the fact already cited that all the known nickel deposits had already been disposed of, seemed to make it doubtful whether any substantial results could be expected from its adoption.

A memorandum by the Director of the Bureau of Mines accompanied the Lieutenant Governor's despatch conveying to Ottawa the Ontario government's reply. It was pointed out that in the existing state of the Canadian nickel industry there was some ground for the apprehension implied in the Admiralty's correspondence that the nickel mined in Canada should not, in a time of emergency, be available for Imperial defence or offence, since by far the larger part of the nickel left Canada in the form of matte to be refined in a foreign country, to wit, the United States, no refining whatever being done at home.

Nickel, which plays so important a part in modern armaments, can now be obtained in commercial quantities practically from only two sources, viz., the Province of Ontario and the penal colony of New Caledonia. It is conceivable that under certain circumstances exports of nickel ore from New Caledonia would be prohibited, or the supply cut off, which would leave the mines of Ontario the only remaining source of nickel. It might then become a matter of urgency to His Majesty's government to procure, and procure quickly, nickel in sufficient quantity to meet large requirements; and if some machinery were not already in existence by which such supplies could be obtained, regardless of the complications or difficulties to which the largely non-British ownership of the mines of Ontario might possibly give rise, a serious situation might confront the Imperial authorities. Whether the power to take possession of nickel ore or nickel matte would of itself be sufficient in the absence of the necessary means of treating Sudbury minerals (which are quite distinct in their character from those of New Caledonia, and require very different methods of treatment) may admit of doubt It would, however, enable the Imperial government to obtain stocks of the raw material, for the refining of which provision would have to be made.

The memorandum concludes as follows:

> It is perhaps not yet too late for the British government, if it entertains any such desire, to acquire nickel lands in Canada, but it would seem that it must obtain them from private owners, since it is problematical whether the Crown domain has much nickel-bearing property left upon it. Should the Imperial authorities continue unwilling to enter the field directly, perhaps the most practical method of ensuring a sufficient supply of nickel at all times would be to vest power say in the hands of the Governor-in-Council to expropriate or take possession of nickel ores, matte, etc., and possibly also the mines themselves whenever the necessity arises, whether for purposes of Canadian or Imperial defence or warfare, paying, of course, the fair value thereof. To enable this to be done, it would seem that legislation would have to be enacted by the Dominion Parliament.

It will be observed that at the date of the despatch, 1904, the Admiralty had not yet decided that Canadian nickel was suitable for the manufacture of armour-plate and other equipment for war. Up to this time all the nickel used in the government arsenals, or by contractors for armour-plate, ordnance, etc., was of New Caledonian origin. In this year, however, the Mond Nickel Company succeeded, after much effort, in convincing the British authorities that Canadian nickel was just as good as New Caledonian nickel, and since that time metal from both sources has been freely accepted.

The question of a supply of nickel from Canada continued to occupy the attention of the Admiralty authorities, and in 1907, Hon. F. Cochrane, then Minister of Lands, Forests and Mines, was asked for information as to the powers possessed by the Ontario government, by which the exportation of nickel ore or matte, from Canada to foreign countries, could be prohibited in case of national emergency, also as to the position of affairs in regard to keeping nickel-bearing lands in British hands.

Mr. Cochrane's reply was to the effect that the government of Ontario had no power to prohibit the exportation of nickel ore or nickel matte to foreign countries, either in time of national emergency or otherwise. As to the ownership of nickel lands, the most important mines were owned by the Canadian Copper Company and the Mond Nickel Company. The former which was much the larger producer, was an American, the latter a British company. There were still remaining nickel-bearing lands, mostly undeveloped, not controlled by either company, but owned by British subjects resident in Canada.

Ontario Offers Bounty on Refined Nickel

In 1907, the Legislature of Ontario decided to try rewards instead of penalties. By the Metal Refining Bounty Act, (7 Edward VII, chap. 14,) a bounty was provided "on refined metallic nickel or on refined oxide of nickel," at the rate of "6 cents per pound on the free metallic nickel, or on the nickel contained in the nickel oxide." Refined metallic copper, or refined sulphate of copper, was also subsidized at the rate of one-half cent per pound on the metallic copper contents. Bounties were provided for metallic cobalt and refined cobalt oxide, and on arsenic made from mispickel ores. Not more than $60,000 was to be paid out in any one year for either nickel or copper. The term of the bounty was to be five years from 30th April, 1907, but a further five-year period, provided in 1912, extended it to 30th April, 1917.

So far as solving the question of refining nickel in Ontario on a large scale is concerned, the Act has not been effective. There is nickel in the silver ores of the Cobalt camp, from which both nickel oxide and metallic nickel have been produced On these, as well as on very considerable quantities of cobalt oxide. bounties have been paid under the provisions of the Act. It may be that the inducements are on too small a scale, but to provide a bounty of 6 cents per pound on the output of nickel say for 1916, amounting to 83,000,000 lbs. would require the very substantial sum of $4,980,000.

House of Commons' Committee on Mines and Minerals

In 1910 the standing committee of the House of Commons on Mines and Minerals, undertook to investigate the nickel question, and particularly to find out why nickel was not refined in Canada. Mr. James Conmee was chairman of the committee. Arthur Wilson, an English engineer, and John Patterson, of Hamilton, who was connected with the Dominion Nickel-Copper Company of that place, were called before the committee. The former alleged the existence of a combination among nickel refiners for the regulation of sales and prices. The government contractors in Europe were granted a special price of 25 cents per pound to prevent them combining to enter the refining business; while other steel trades paid 35 cents per pound, and white-metal workers and platers from 40 to 70 cents per pound, according to the quantities consumed. These high prices had the effect of restricting the demand for refined nickel. New Caledonia could not compete with Ontario as a source of nickel supply, but the Rothschilds in the former place, and the International and Mond companies in the latter, worked in agreement, limiting the output, fixing the price, and dividing the market. Mr. Wilson placed the cost of producing refined nickel at 15 cents per pound, and the profit at about 18 cents per pound. Notwithstanding there was abundance of ore at Sudbury not owned by existing companies, it was practically impossible to establish a rival industry in the face of the opposition of the International Nickel Company, which was a very powerful concern. Besides, the large consumers of nickel were tied up with long-time contracts. Mr. Wilson's remedy was to levy an export duty on the matte, and to bonus the manufacture of nickel-steel in Canada. Nickel refining and cognate industries would thus be established here. The imposition of an export tax on matte would not, in Mr. Wilson's opinion, outweigh the advantages of the Ontario nickel mines, or cause the International company to bring their ore from New Caledonia. Mr. Patterson narrated the difficulties which had beset him and his associates in trying to enter the nickel business in the Sudbury region; they had been checkmated in their financing by adverse influences in New York; they had found the duty of $120 per ton on refined nickel going into the United States a serious obstacle; the existing combination controlling prices and sales was very formidable; and in the end they sold their Sudbury lands to certain capitalists in Ottawa.[1] There was no doubt that nickel could be refined in Canada, but the United States duty on the refined article created a serious situation. He advocated the imposition of an export

[1] J. R. Booth, Ottawa, and M. J. O'Brien, Renfrew. These gentlemen subsequently sold to the British America Nickel Corporation, Limited.

tax with the view of bringing about the abolition of the United States duty. Mr. Patterson thought that nickel could be produced in Canada for about 15 cents per pound.

The Case for the International Nickel Company

The other side of the case was presented to the committee by Wallace Nesbitt, K.C., A. P. Turner, president of the Canadian Copper Company, E. F. Wood, vice-president of the International Nickel Company, and George M. Colvocoresses, mining engineer. The evidence given by these gentlemen, with the exception of Mr. Colvocoresses, who spoke from personal experience about conditions in New Caledonia, may be summarized thus:—

The development of the Sudbury nickel industry was traced, and it was asserted that the International Nickel Company, which was formed in 1902, was merely a consolidation of the mining and refining industries formerly carried on independently by the Canadian Copper Company and the Orford Copper Company respectively, and was in no sense a trust. The latter company had a cheap and efficient process for refining matte. Proximity to chemical and oil works at Bayonne, New Jersey, gave it unusual facilities for operating this process economically, in addition to low freight rates for assembling other necessaries such as coal, coke, acid, etc. The companies concerned, first, the Canadian Copper Company, and later the International Nickel Company, would be glad to refine in Ontario. They had spent hundreds of thousands of dollars in attempts to develop a refining process to take the place of the Orford method, and one which could be operated here. They had experimented with the processes put forward by Garnier, Hoepfner, and others, both in the United States and at Copper Cliff. They had had a representative for a year in the Mond Nickel Company's works in Wales, studying the operations of that plant, and had tried electrolytic and all other known expedients for the refining of nickel, but in vain. They had failed to find a substitute for the Orford process, which being dependent upon cheap chemicals and fuels, could not be worked successfully at Copper Cliff. Certainly nickel could be refined in Canada, but not at a price which would enable it to compete with nickel produced abroad. If the industry were attempted in southern Ontario, the sulphur fumes would be considered a nuisance. An export duty on matte would close up the works at Copper Cliff, and consequently the mines also, in which case the company would bring ore or matte from their nickel lands in New Caledonia to be refined at Bayonne. The New Caledonian ore is easier and less expensive to refine than that from Sudbury; the disadvantages are, the heavy freight rates and the great distance from New York. As to profits, the profit on refined nickel was about 7½ cents per pound. There was no understanding between the International Nickel Company and the Société le Nickel or the Rothschilds. On the contrary, they were rivals and competitors.

The evidence was reported to the House of Commons, but it does not appear that any action by that body was either recommended or taken.

Finally, in September 1915, the present Commission was appointed to study the question, and to report, among other things, whether any insuperable difficulty prevents the refining of the nickel-copper ore of Sudbury, within the boundaries of the Province in which the ore is produced.

CHAPTER II

Historical Sketch of Nickel Discoveries

Beginnings of Mining on North Shore of Lake Huron

Sixty years ago that part of Upper Canada lying north of Lake Huron, was almost unbroken wilderness. Save where devastated by fire, it was densely wooded, mostly with pine and other conifers. The inhabitants were scattered remnants of the old Indian tribes, who lived by fishing, trapping and hunting. The fertile southwestern peninsula of the Province, lying in the angle formed by the great lakes, was filling up with immigrants from across the seas, but the territory fronting on the north shore of Lake Huron had little attraction for settlers. The virgin forests stretching from Lake Nipissing to Sault Ste. Marie were almost as remote from the clearings and settlements of Upper Canada as if they had been in Alaska. Fertile areas there were, but of comparatively small extent. Trappers and fur traders travelled the route up the Mattawan river, across Lake Nipissing and down the French river, or pushed their canoes up the Wanapitei, the Mississaga, the Thessalon and other streams which drained the watershed sloping down to Lake Huron; but practically the only fore-runners of civilization who had here and there broken in upon the solitude of the "North Shore" were the lumberman and the miner; and their numbers were few.

White and red pine, then almost the only kinds of timber which had any value in commerce, still stood in large quantities in the Ottawa valley and along the rivers running into Georgian Bay. Consequently the lumber trade, which at a later period was to supply the sawmills of Michigan with great rafts of pine saw-logs, towed in booms across the lake, had in this region scarcely begun. The sale of timber limits, by which the Crown dispossessed itself of forests covering 3,200,000 acres back from the shore of the lake, and including a large part of the Sudbury mining area, was not held until 1872.

Reconnaissances by Logan and Salter

In a remarkably able and full report dated 31st March, 1857, and dealing with a great variety of subjects within the scope of his department, Hon. Joseph Cauchon, Commissioner of Crown Lands, treats of the wild lands of the Province of Canada, as constituting the home of future settlements, and endeavours to estimate the value for agricultural, mining and lumbering purposes of the territory north of Lake Huron. The materials for such an estimate were scanty. The principal sources of information drawn upon by the Commissioner are the report of Sir William Logan, Provincial Geologist, made in 1848[1], and the report[2] by A. P. Salter, Provincial Land Surveyor, who in 1855, at the direction of the Commissioner, had ascended the various rivers emptying into Lake Huron from Sault Ste. Marie eastward, and furnished a general description of the tract.

[1] Report on North Shore of Lake Huron, 17th January, 1849. (Geol. Sur. Can., 1847-8.)
[2] Journals Leg. Assy., 1856, Appendix 37.

Logan's report presents such information as was then available regarding the geology and minerals. It is, in fact, largely taken up with a description of the copper ore deposits at Bruce mines, in examining which he and his assistant, Alexander Murray, had spent the summer of 1848. Although the ore at Bruce mines contained no nickel, this earliest effort at mining on the north shore merits a few words here, not only for its historic interest, but also for the spirit with which it was begun and continued against a crowd of difficulties.

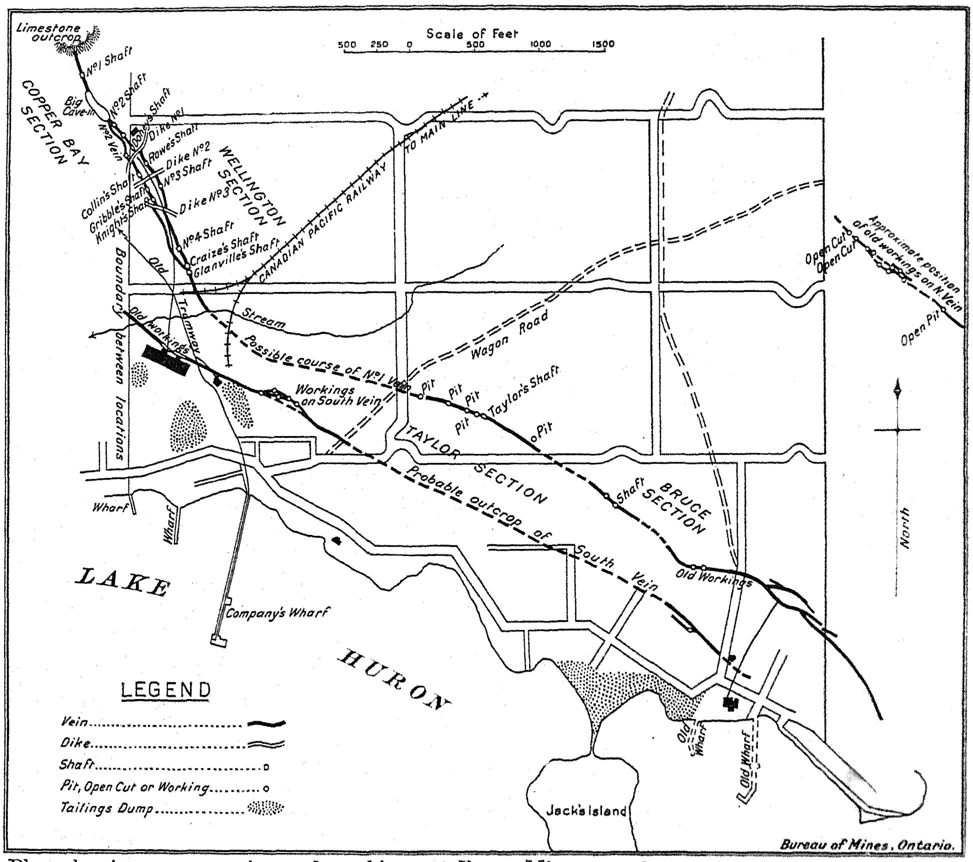
The discovery of large and showy veins of copper ore in quartz led to the opening of the Bruce mines in 1846, and for a number of years thereafter the merchants and professional men who composed the directorate of the Montreal Mining Company were working with vigor to realize the fortune which they believed the veins to contain. A bustling mining village with offices, stores and warehouses rose on the shore of the lake, and concentration works were erected in which the copper ore was treated before being shipped to England. Attempts at smelting even were made at a later date, but these did not prove successful and were discontinued. Logan describes and maps the lodes which had been discovered at Bruce mines, and records that up to July, 1848, some 1,475 tons of copper ore and undressed vein-stuff had been raised, the average assay of which was 8.01 per cent of copper.

Unfortunately, after Logan's visit, as work proceeded the ores became poorer, and the original company after many tribulations, reduced the scale of its workings and sold off the western part of its property, the purchasers being known as the West Canada Mining Company. The new owners found fresh veins resembling the original discoveries, but even richer, and the Wellington mines were opened upon them; subsequently, they also acquired the Huron Copper Bay location. From these deposits the West Canada Company was enabled to pay several handsome dividends, and it eventually took over from the Montreal Mining Company the entire Bruce Mines location. But the old troubles recurred. The lodes became leaner as they were sunk upon, and the heavy expense and losses of copper in concentrating, together with the high costs of freights to England, at length extinguished profits altogether.

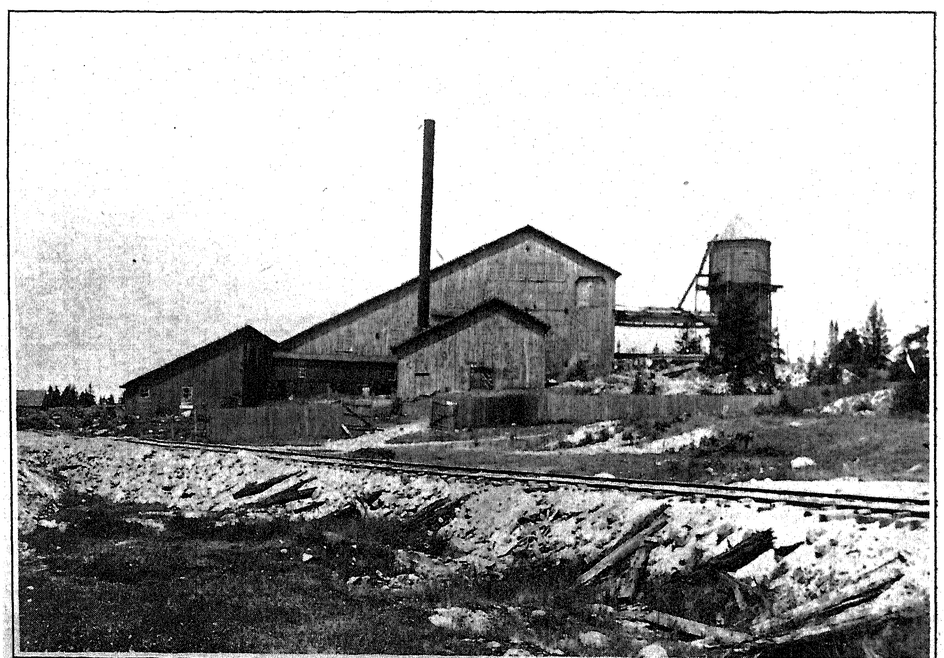
No other mineral workings are mentioned in Sir William's report, doubtless for the reason that there were no others of importance in the region, though discoveries of mineral, mainly copper ore, had been made elsewhere. "Copper pyrites," he states, "in one instance was accompanied by rutile, and in another by the arseniuretted sulphuret of iron and nickel containing a trace of cobalt." The latter reference is most probably to the nickel mineral found at the Wallace mine, spoken of below. Sir William was favourably impressed by the prospects for copper mining on the north shore, being persuaded, he says, that although some of the lodes (*i.e.*, at Bruce Mines), vastly surpassed in richness any which came within his observation in the interior, others would yet be found to equal them. He sums up by saying:

> In no part of the country visited from the vicinity of Sault Ste. Marie to Shebawenahning[1] was any great area wholly destitute of cupriferous conditions, and it would appear singular if a region extending over a space of between one and two thousand square miles, and so marked by indications, did not in the course of time yield many valuable results.

[1] Now Killarney.



Plan showing copper veins and workings at Bruce Mines, on the north shore of Lake Huron.



Mill at Bruce Mines, on the north shore of Lake Huron.

As will afterwards be seen, Mr. Salter was a good surveyor, but he expressly disclaims any skill in geology. As regards minerals, he contents himself in his report with saying that indications of such in the most sterile sections were constantly met, which led him to hope that at some future period these portions would serve to increase the revenue of the country.

The resources in timber were more easily appraised, and Salter's report leaves no doubt as to the great extent of the forests then standing on the north shore. These consisted not only of pine, hemlock, spruce, cedar and balsam, but also, though in lesser degree, of hardwoods such as elm and oak. At that time only one sawmill was to be found on the north shore, that erected at Collins Inlet by Messrs. Waddell and Murray. Salter tells us it was driven by water power and had two upright saws, a circular edger and a siding machine. In this region the lumberman has now been at work for forty-five years, and his labours, together with the numerous and disastrous fires, have made sad inroads upon the forests. Nevertheless, they still provide annually large quantities of timber. In consequence of the government imposing what are called the "manufacturing conditions," which prevented the export of sawlogs cut under license on the Crown domain, and required them to be sawn into lumber or otherwise manufactured within the Province, the rafting of sawlogs across the Lake to Michigan came to a close in the year 1898, and all such timber has since been sawn in Ontario.

William Gibbard's Report

An interesting glimpse at the early mining operations is obtained from a report made to the Provincial government in 1860 by William Gibbard, P.L.S. A condition of the grant of mining locations by the Crown at that time was that they should be actually worked, and Gibbard was commissioned to visit all the locations that had been granted, and to report whether this condition was being fulfilled. His report is published in the Report of the Commissioner of Crown Lands for 1860 as Appendix No. 22.

At the Bruce Mines (east part Cuthbertson location) Gibbard found employed 25 miners and 25 labourers. For several years all work had been carried on by individual miners on their own account, either on tribute or royalty. The company kept the machinery in repair, and the miners got the ore into merchantable shape. For 13 per cent. dressed ore the miners were paid by the company $112 to $128 per ton, and more for ore of a higher percentage. The royalty miners paid all expenses and 5 per cent. to the company for the use of the ground. The deepest shaft was 306 feet. The total shipments from 1848 to 1860 were 10,729 tons (dressed ore), valued at $661,789; the total expenditure was $1,326,000. The Wellington (west part Cuthbertson location) and Huron Copper Bay mines (Keating location) were in the heyday of their prosperity. The company was known as the Wellington Huron Bay and West Canada Mining Company, and it held its lands under lease from the Bruce Mines and Copper Bay companies. At the Wellington 330 hands, of whom 125 were miners, were employed. The copper shipped in 1859 amounted in value to £38,728 12s. 3d. sterling, and the dividend for that year was £6,350, the capital invested being £20,000. The superintendent estimated that the shipments for 1860 would clear, over and above all expenses, sufficient to reimburse the shareholders their full investment, or, added to the

dividend for 1859, would equal the whole capital. On the Copper Bay property, the lodes lately opened up were rich and very promising. For the eight months ending 31st July, 1860, the expenses of receiving the ore from this location were £3,852 10s. 5d. sterling currency; the products were £7,485 10s., and the profit within a fraction of 50 per cent. The ore was all shipped to England via Buffalo and New York or Baltimore; if by Buffalo, the freight charges were £2 per ton, if by New York or Baltimore $8.60 per ton. The ores shipped were a mixture of peacock, horse-flesh, yellow and gray. Gibbard comments enthusiastically: "I doubt whether there is a safer or more promising investment in Canada."

From first to last the production of copper from this group of mines amounted to a considerable quantity, given by a competent authority[1] as 9,653 tons of copper, valued at $3,300,000. The active career of Bruce Mines came to an end in 1875, and although several attempts have been made by subsequent owners to bring about a revival of mining, they have been without much success.

For many years vast heaps of "skimpings," as the silicious tailings from the ore-dressing machinery were called, remained to testify to the scale upon which operations had been carried on. These are all now gone. Most of the material was removed and used for ballasting the road-bed of the Sault Ste. Marie branch of the Canadian Pacific railway, and the remainder was conveyed to the Sudbury smelters to be used as linings for the converter furnaces. The latter use permitted the recovery of most of the copper contained in the tailings, said to be on an average not less than one per cent. It is known, however, that considerable quantities of these skimpings contained up to 2 per cent. of copper. The mines have recently been bought, and are now being worked by the Mond Nickel Company, which naturally prefers cupriferous to barren quartz for use in its converters at Coniston.

However, the mining industry was of slow growth. That little work outside of Bruce Mines was being done is clear from the work of Gibbard already quoted, made twelve years after that of Logan. Out of sixteen properties granted on the north shore of Lake Huron, several of them comprising two or more locations, Gibbard found that on five no work of any kind had been done; on eight others openings had been made, but had been abandoned or were lying unworked; and on three only were mining operations actually being carried on. These were Bruce, Wellington and Copper Bay, and Rankin's. The last mentioned was at Root river, where a couple of shafts were being sunk, one having reached a depth of 24 feet, and the other of 33 feet. Rankin's location and the work done on it looked good to Gibbard, who endorses the enterprise thus: "If any mine ought to succeed from the result of a sensible and economic commencement, from the richness of the lode, from the position close to the great highway of navigation, and also on the immediate line of the great northern road, this should." Gibbard's prophecy, however, failed of fulfilment, for the Rankin location on Root river never developed into a mine.

First Discovery of Nickel

The first discovery of nickel in Ontario was at the Wallace mine, a short distance west of the point where the Whitefish river enters Lake Huron. Sir

[1] H. J. Carnegie Williams; The Bruce Mines, Ontario, 1846-1906; Journal Can. Mg. Inst., Vol. X, 1907. Mr. Carnegie Williams was manager at Bruce Mines in 1906.

William Logan's assistant, Alexander Murray, who had spent the early part of the season of 1848 in assisting his chief to examine the Bruce Mines and adjacent territory, devoted the latter part to surveying the coast farther to the east, and included the Wallace mine location in his visit. Here some six mining blocks, containing in all 2,000 acres, had been taken up[1] by the Upper Canada Mining Company, on the strength of a discovery of copper pyrites accompanied by nickel. Murray says[2] that among the quartzose and chloritic slates close to the shore, a shaft had been sunk for several feet, and a channel in the surface rock excavated for a short distance on either side. These openings at the time of his visit were filled with water. All mining operations had been suspended, and the opportunity of making a satisfactory examination was lacking. He noted, however, in the drifted channel at the surface, strings and bunches of copper pyrites, which appeared to be interlaminated irregularly with the slates of the formation, and specimens of "a very pure yellow sulphuret of copper," accompanied by an ore of nickel and arsenical iron pyrites, were found in the same position. Murray's visit was apparently too short to enable him to satisfactorily determine the geological conditions of the location, and he failed to discover a definite vein or any surface characteristics indicating the existence of one. He submitted a specimen of the nickel-bearing material, as free as possible from copper pyrites, to T. Sterry Hunt, who reported[3] as follows upon it:

The specimen was a mixture of a steel gray arseniuret, the species of which I have not yet determined, with white iron pyrites, and probably some arsenical sulphuret of iron. As the immediate object of the analysis was to determine the proportion of nickel and other valuable materials in the crude ore, a mass weighing forty-five ounces was reduced to powder, and submitted to analysis by the usual methods, with the following results:

Iron	24.78	
Nickel, with a trace of cobalt	8.26	
Arsenic (mean of two determinations)	3 57	
Sulphur	22.63	
Copper	0.06	
		59.30
Silica	28.40	
Carbonate of lime	4.00	
Magnesia	4.40	
Alumina	3.21	
		40.01
		99.31

In the process of dressing the ore, the earthy parts being removed by washing, the composition of the ore in 100 parts, as deduced by calculation from the above, would be

Iron	41.79
Nickel, Cobalt	13.93
Arsenic	6.02
Sulphur	38.16
Copper	.10
	100.00

The small proportion of arsenic shows that a great portion of the metals must exist as simple sulphurets, and that, contrary to what might have been supposed at first sight, a large part of the grayish ore must be white iron pyrites.

[1] The locations at the Wallace Mine, 2,000 acres, were not patented until 4th March, 1864, but the plan of survey was made by Alexander Vidal, P.L.S., in 1848, the year of Murray's visit.

[2] Geol. Sur. Can, 1848-9, pp. 43-5.

[3] Ibid, pp. 61-2.

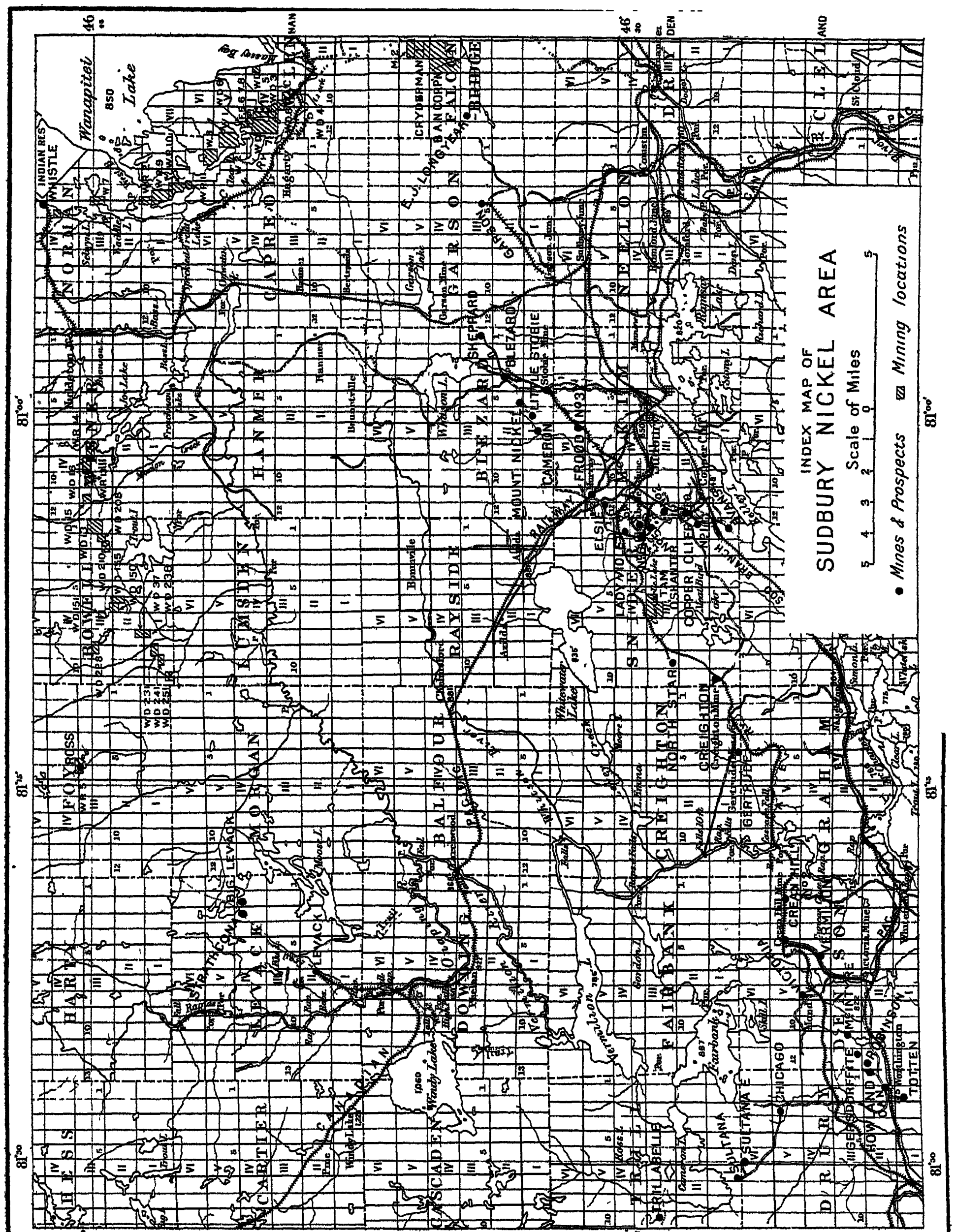
No mine, either of copper or nickel, has ever been developed on the Wallace Mine location, which from the days of Murray and Hunt has remained practically undisturbed. Subsequent observers have also failed to discern any ore body, and in the report of the Commission on the Mineral Resources of Ontario (1890) the Commissioners have the following to say:[1]

Some particles of copper pyrites are to be seen in the rock at the dump, but otherwise no sign of vein or vein matter or ore of any value. It may be said that at the places visited by us on this property there appeared to be small masses of copper pyrites and iron pyrites, and in one place some nickeliferous and arsenical iron pyrites in a quartz stringer in dioritic rocks, chloritic schist, and to a less extent in quartzite, but we were unable to detect any satisfactory sign of a permanent vein, or of segregated masses of mineral matter.

Nickel on Michipicoten Island

In the Geology of Canada, 1863, page 505, Hunt mentions the occurrence of nickel on Michipicoten island, but no particulars are given regarding the deposit or its exact location, and the date of discovery is alluded to only casually as "a few years since." Two varieties of ore are described, both said to be from the same vein, which was found cutting a bed of amygdaloid. The first sample was a mass of ore associated with quartz, having a brilliant metallic lustre, and a colour varying from tin-white to bronze yellow. Its hardness was 5.0, and its specific gravity from 7.35 to 7.40. The mineral was variable in composition. Four analyses are given. Arsenic was present in samples one and two to the extent of 37.36 per cent. and 44.67 per cent. respectively; copper ran from 10.28 per cent. in sample four to 44.70 per cent. in sample one, while the nickel contents of the four samples were 17.03, 24.55, 27.29, and 36.39 per cent. respectively. It was inferred from calculations that these varying results were due to the ore being a mixture of nickeline (niccolite or kupfer-nickel)—an arsenide of nickel containing 44.1 per cent. of nickel and 55.9 per cent. of arsenic—and domeykite, an arsenide of copper, containing 71.7 per cent. of copper and 28.3 per cent. of arsenic. The second variety of ore occurred as a gangue of native copper and native silver, both being scattered through it in grains. The mineral was amorphous, greenish yellow or apple-green in colour, with a waxy lustre and conchoidal fracture. It was very soft, polishing under the nail, and falling to pieces when immersed in water. It was decomposed by acids, and was found to be essentially a hydrated silicate of nickel. Analysis of one specimen dried at 212 F. gave oxide of nickel 30.40 per cent.; another dried at a higher temperature yielded oxide of nickel 32.20 per cent., and contained besides traces of cobalt and copper, being identical with nickel-gymnite or genthite. A third specimen, which contained small grains of the native metals disseminated, gave silver 2.55 per cent., copper 18.51 per cent., and oxide of nickel 20.85 per cent.

But the discoveries at the Wallace mine and on Michipicoten island, while significant as showing the presence of nickel, have so far not been shown to be of considerable extent or of commercial value. Large industries cannot be built up on mineral occurrences barely sufficient in size to provide cabinet specimens. The real nickel field of Ontario is the Sudbury district, and the story of the discovery of nickel ore there is interesting.



Index Map of Sudbury area, showing townships, lots and concessions.

The Creighton Mine Foreshadowed

In 1856 Salter, who in the previous year had made the exploratory trip[1] along the northern shores of lakes Huron and Superior already referred to, was again in the field for the purpose of running base, meridian and range lines preparatory to a general survey and subdivision of the territory lying between lake Nipissing and Sault Ste. Marie. Starting at a point on the Sturgeon river near its entrance into lake Nipissing, Salter ran a base line westward. On arriving at Whitefish lake he surveyed a meridian line due north twelve miles, which was continued the following year eighteen miles farther. In his report[2] Salter remarks that the character of the country on the meridian line closely resembled that of the last section of the base line from the Wanapitei river to Whitefish lake, except that the valleys were broader and the soil generally lighter in character. He says:

> Between the fifth and eighth mile on this line I discovered considerable local attraction, the needle varying from 4 degrees to 14 degrees westerly. The existence of iron was plainly discernible on the rock.

Turning to the field notes of the survey, on file in the Department of Lands, Forests and Mines, it is found that the normal variation of the magnetic needle for the first five miles of the meridian line was about 3 degrees and 30 minutes west, but that at six miles 30 chains and 50 links, it deflected to 5 degrees 30 minutes west, and continued to show marked variations ranging to 14 degrees 10 minutes west at 7 miles 33 chains 50 links, and approaching the normal again only at 8 miles 17 chains 25 links. In the marginal column for remarks Salter makes the note, "Appearance of iron in trap."

Although not a geologist, Salter recognized the significance of this marked and extended attraction, and meeting Murray, who during the same season was continuing the geological explorations near lake Nipissing and on the north shore of lake Huron, upon which he had also been engaged during the two previous years, he mentioned the matter to Murray, and gave him particulars of the exact locality.

In reporting on his season's work[3] Murray tells how he followed up Salter's hint:

> At the fifth mile a dingy green magnetic trap, with a large amount of iron pyrites, forms a ridge, and that rock, with syenite, continues in a succession of parallel ridges to the seventh mile, beyond which the country becomes low and marshy. These parallel ridges strike nearly east and west, and small brooks or marshes occupy the intermediate valleys.
>
> Previous to my visit to Whitefish lake, I had been informed by Mr. Salter that local attraction of the magnet had been observed by himself, while he was engaged in running the meridian line, and he expressed it to be his opinion that the presence of a large body of iron ore was the immediate cause. When, therefore, I came to the part indicated by Mr. Salter, I made a very careful examination not only in the direction of the meridian line, but for a considerable distance on each side of it, and the result of my examination was that the local attraction, which I found exactly as described by Mr. Salter, was owing to the presence of an immense mass of magnetic trap.
>
> The compass was found, while traversing these trap ridges, to be deflected from its true bearing upwards of ten degrees at several different parts, and in one place it showed a variation of fifteen degrees west of the true meridian, or about twelve degrees from the true

[1] In this exploration Salter was accompanied by Count de Rottermund in the capacity of geologist. De Rottermund's report is to be found in the Journals of the Legislative Assembly of the Province of Canada, 1856, Appendix 37. It is of little value, owing to the extraordinary theories regarding geological and mineralogical phenomena which the author entertained.

[2] Rep. Com. Crown Lands of Canada, 1856, p. 265.

[3] Geol. Sur. Can., 1853-6, pp. 180, 181.

magnetic north. Specimens of this trap have been given to Mr. Hunt for analysis, and the result of his investigation shows that it contains magnetic iron ore and magnetic iron pyrites generally disseminated through the rock, the former in very small grains; titaniferous iron was found associated with the magnetic ore, and a small quantity of nickel and copper with the pyrites.

Murray further states:[1]

The magnetic trap discovered on Mr. Salter's meridian line north of Whitefish lake was observed to hold yellow sulphuret of copper occasionally; and Mr. Hunt's analysis of a hand specimen of the rock, weighing ten ounces, gave twenty grains of metalliferous material, of which eleven were magnetic, and consisted of magnetic iron ore, with a little titaniferous iron ore, and magnetic iron pyrites containing traces of nickel. The nine grains of non-magnetic mineral consisted of iron pyrites containing from two to three per cent. of copper and about one per cent. of nickel.

The location of this nickeliferous material is easily found. Salter's meridian line was retraced in 1883, and was made to form the west boundary of the townships of Waters[2] and Snider.[3] The point which is located 43 chains north of mile post VI on Salter's meridian is one and the same point as that which is located 43 chains north of the southwest corner of Snider on the west boundary of the township. It was here that Salter found unusual deflections of the compass and here noticed "the appearance of iron in trap." Here also, or near by, it certainly was that Murray discovered the "immense mass of magnetic trap,"[4] containing disseminated sulphides of nickel and copper. This locality is only 200 yards west of the great open pit of the Creighton mines. Unquestionably then, Murray walked over and examined the long gossan-stained ridge, at the foot of which in later years the greatest nickel mine in the world was discovered.

Salter and Murray duly reported to the government, which put their reports in print, and there they may be found to-day by those interested in the early history of the mining industry of Ontario. Doubtless the real significance of the discoveries these pioneers had made was not apparent to the public of their day, or

[1] Geol. Sur. Can., 1853-6, p. 189.

[2] The first six miles on Salter's meridian, which now constitutes the west boundary of Waters township, was retraced by W. R. Burke, O.L.S., in 1883, who states in his field notes filed in the Department of Lands, Forests and Mines, as follows: "From my south boundary I worked northward, retracing Provincial Land Surveyor Salter's principal meridian (which is my west boundary) as I proceeded. This I found somewhat difficult to do in the northern part of the township, as it has been overrun by fire, some of it the second time, thus destroying nearly every trace of the line. Succeeding, however, in tracing it, I failed to find his post marked "vi miles," which you instructed me would be the northwest angle in my township. . . . In Provincial Land Surveyor Salter's meridian I found a slight bend about the fourth mile." Burke mentions that he met with no deposits of mineral in surveying the township.

[3] Snider township lies directly north of Waters The west boundary of Snider is a continuation to the north of the west boundary of Waters, and therefore of Salter's meridian line between mileages 6 and 12. Snider was surveyed by I. L. Bowman, O.L.S, in 1883, but his notes do not state that he found any trace of Salter's old line. Bowman met with no valuable minerals in the course of his survey, which shows that the Creighton mine had not been rediscovered up to that time, or at any rate was not generally known; the west boundary of Snider township is only 200 yards from the open pit of the Creighton mine. The township of Creighton, which is directly west of Snider, was surveyed in 1884 by J. McAree, O.L.S. He noted a disturbance of the compass in passing over the rock at the southeast corner of the township, *i.e.*, near the Creighton deposit. This rock was found in after years to be norite. The Gertrude nickel mine is also situated in this locality, being on the south half of lot 5, in the first concession of Creighton.

[4] Geol. Sur. Can., 1853-6, p 180.

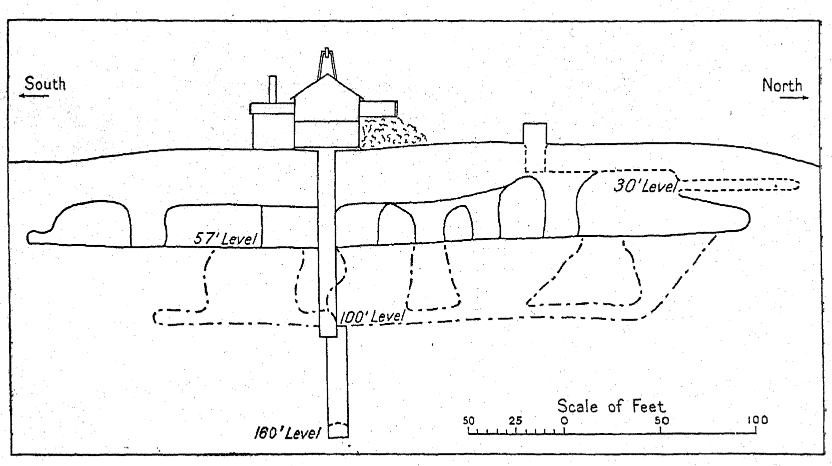
even to themselves. Probably the financial results of the mining ventures on the north shore, virtually confined as these had been to the Bruce Mines copper group, were not of a kind to awaken lively hopes of large profits and quick returns. Nickel was not in great demand sixty years ago, even though its price was many times that of copper. A mineral deposit on Salter's principal meridian line, at least thirty miles north of the navigable waters of lake Huron, in a rough country entirely destitute of means of communication, was so inaccessible as to be of little immediate interest. At any rate, the mass of magnetic trap and the reports alike passed out of mind, and were only recalled when the Creighton mine was rediscovered; and this did not take place until the construction of the Canadian Pacific railway in the early eighties had brought to bear on the latent resources of the Sudbury region the vivifying influences of transportation and population.

Finding the Murray Mine

The building of the railway through this region in 1883 quickly led to the discovery that it was rich in minerals. The first deposit of nickel ore to be actually found was what afterwards came to be known as the Murray mine. The right of way for the railway was cleared for some distance west of Sudbury in 1883, and in August of that year a blacksmith on the construction gang named Thomas Flanagan observed an area on the right of way covered with gossan, and dug some holes in it which showed copper sulphide. When the "grade" reached the spot, a cutting in the rock was necessary, which exposed the deposit. A little later, the attention of John Loughrin, of Mattawa, afterwards for years member of the Legislature for Nipissing, who had a contract for making ties on that section of the line, was attracted by a deposit of "red mud" on the wagon road close by, and by the appearance of mineral in the rock cut. Doubtless others afterwards remembered that they, too, had noted the peculiar appearance of the place. This led to an application being made to the Department of Crown Lands by Thomas Murray on 25th February, 1884, for permission to purchase the lot, 11 in the fifth concession of the township of McKim. It was accordingly patented to himself, William Murray, Henry Abbott of Brockville, and John Loughrin, on the 1st of October, 1884, the price paid being the statutory one of one dollar an acre. The mine received its name from the Murray brothers, Thomas and William, then well-known merchants of Pembroke. The former was a member for several terms in the Legislature at Toronto, and also sat for Pontiac county, Que., in the House of Commons at Ottawa.

The patentees sold to H. H. Vivian and Company, of Swansea, Wales, who began mining operations in October, 1889, after having tested the quality and character of the Sudbury ores by smelting and refining them in their Swansea works. A smelter was erected and blown in, September, 1890; a second furnace was added a year later, and a third in 1892. These made a low grade matte, containing about 8 per cent. of nickel, which was bessemerized to a product carrying 35 or 40 per cent. nickel and 20 to 25 per cent. copper. Mining and smelting was carried on with more or less success until 1894, when the mine was permanently closed down. The property remained unworked until it was sold for $75,000 to E. R. Booth, M. J. O'Brien and associates, who prospected it by the diamond drill,

The photograph illustrates how the building of the Canadian Pacific Railway was the means of discovering a great nickel-copper mine; namely, the Murray. The railway cut intersects the ore body, the latter being shown to the left of the track beside the man. Photograph taken Sept. 2nd, 1916.



Old workings at Murray mine. The British America Nickel Corporation is now beginning to work this mine on a large scale.

and were successful in discovering a very large tonnage of ore previously unknown—now placed at eight or nine millions of tons. Messrs. Booth and O'Brien in turn sold to the British America Nickel Corporation, Limited, which now owns and proposes to work the mine on an extensive scale.

The copper exposure in the C.P.R. right of way gave public notice of the discovery of mineral, and as soon as the snow had disappeared in the spring of 1884, prospectors were attracted to the locality, and took to the bush in the hope of finding other deposits.

Prospecting in the early stages of the Sudbury field was entirely a matter of searching for outcrops, and the prospectors, many of whom had had little or no previous experience in the work, soon mastered such rudiments of geology as they found essential. Their favourite rock was "diorite"—now known in the Sudbury literature as norite—and the unfailing surface indication was a "burn" or gossan-covered area. Prospectors quickly established the rule that ore bodies were to be found at or near a "diorite" contact, and by their untiring labours during the first three or four years located most of the important deposits that have yet been found. The region was not mountainous, and the numerous waterways, made up of lakes, rivers and creeks, enabled the prospectors to penetrate with their canoes to almost any quarter and in almost any direction; but on the other hand, there was the disadvantage that the surface of the country was rough and broken, and covered with forest growth, green or already burnt. Rocky ground was plentiful, but the mantle of moss had sometimes to be removed before the formation could be inspected. Forest fires were of frequent occurrence, and the assistance they afforded by clearing the ground of timber and moss gave rise to the suspicion that in some cases the prospectors, if not actually guilty of setting out fire, were at any rate indifferent to its occurrence, and lukewarm in attempting to extinguish it. Other advantages the prospectors enjoyed were found in the greater part of the territory having been surveyed into townships, concessions and lots, thus permitting any finds to be easily and accurately located, and the presence of the railway, which facilitated travel and made supplies abundant and cheap.

No. 4 and No. 6 Mines

Naturally their search was directed first of all to the neighbourhood of the first find. Among the early prospectors was Rinaldo McConnell, and in point of time his discovery of what was afterwards called by the Canadian Copper Company No. 4 mine, situated on the south half of lot 1 in the fourth concession of the township of Snider, was the second ore body to be located in the Sudbury area. McConnell on 16th May, 1884, applied on behalf of himself and Joseph Riopelle for this parcel and also for the southeast quarter of lot 2 adjoining, and the land was patented to them 25th July of the same year. Some years ago No. 4 mine was worked by the Canadian Copper Company, and yielded 43,700 tons of ore averaging 2.91 per cent. nickel and 1.26 per cent. copper, but it has been idle now for a long time. On the same half lot is situated No. 6 mine, or the Clarabelle deposit, from which 4,048 tons of ore were taken by the Copper Company in 1899 and 1900, the average contents of the ore being 1.99 per cent. nickel and 1.69 per cent. copper. The probabilities are that there is still ore in these deposits, but there is no necessity for the company to work them at the present time.

Rinaldo McConnell's connection with the Sudbury nickel region, begun at this early date, has continued until to-day. Physically robust and a man of energy and intelligence, Mr. McConnell in the capacity of prospector and middleman has played no small part in the development of the nickel-copper industry.

The Elsie Mine

The Elsie mine is situated on the south half of lot 12 in the fifth concession of the township of McKim, adjoining the Murray mine location. It was applied for on 9th May, 1884, by Henry Totten, and patented to him 2nd March, 1888. The discoverer was Francis Charles Crean. The property passed into the hands of the Lake Superior Power Company, which began work on the deposit in July, 1900. After making the necessary railway connection, the company shipped the ore to its smelter at the Gertrude mine, the first shipment being made 26th October, 1901. Work was stopped in 1902, and the company failing in 1903, nothing further has been done. While the mine was in operation 40,635 tons of ore were mined and shipped.

The Elsie mine, like the Murray, is now owned by the British America Nickel Corporation, and the whole property is sometimes called the Murray-Elsie.

Locating the Frood or No. 3

Another of the early prospectors was Thomas Frood, who had been a wood ranger in the employ of the Crown Lands Department, and was familiar with the physical features of the Sudbury area. Mr. Frood relates[1] that having heard from one William Nelson, a trapper, that there were indications of mineral on a creek in the northern portion of the township of McKim, he set out on 18th May, 1884, accompanied by A. James Cockburn, another prospector, to examine the locality. He succeeded in locating a vein of pyrites on lot 7 in the sixth concession, and traced it across the boundary to lot 6. A dispute afterwards arose between the two prospectors, which they settled by allotting lot 6 to Cockburn and lot 7 to Frood. Cockburn's claim was transferred to J. H. Metcalf and W. B. McAllister, in whose names the grant issued on 16th July, 1884. Frood took out the patent for the south half of lot 7 in the same month. The mine subsequently opened on this deposit, though not containing the richest ore, has proven to be the largest of the great ore bodies of Sudbury so far developed, and bears the name of Frood, who was a man of education and ability. It is also known as No. 3 mine of the Canadian Copper Company, which now owns the bulk of the deposit.

The Frood was not opened until 1899; from 1900 to 1903 110,545 tons of ore were raised, and the mine then remained unworked until 1914. Extensive borings by the diamond drill have proved the existence of an enormous reserve of ore, estimated to be not less than 45 millions of tons. In 1913 and 1914 preparations were made for a large production, as the company anticipated that henceforward much of their ore would be drawn from the Frood, instead of from the Creighton. A town site was laid out, a water system installed, and numerous dwellings erected for the workmen and officials. Meantime drilling operations had

[1] Letter dated 25th June, 1885, on file in Dept. of Lands, Forests and Mines.

been going on at the Creighton, the result of which was to show that mine to contain supplies of ore sufficient for many years to come. The necessity for working the Frood no longer existed, and the mine was closed in 1915. In 1914 and 1915 174,354 tons of ore were taken out, making the total production from the mine 284,899 tons, the average contents of which were 2.05 per cent. nickel and 1.45 per cent. copper.

Much the larger portion of the ore body is on lot 6, but part is on the south half of lot 7 adjoining, called the Frood Extension mine, and owned by the Mond Nickel Company. The average contents of the ore extracted from the Frood Extension were: nickel, 2.15 per cent.; copper, 2.22 per cent.

The Worthington Mine

The Worthington mine, south part of lot 2 in the second concession of the township of Drury, was next in the order of discovery. This also was found on the right of way of the Canadian Pacific railway, Algoma branch, and is about twenty-five miles southwest of Sudbury. On 14th June, 1884, F. C. Crean applied to the Department of Crown Lands for a tract comprised within the southeastern four square miles of timber berth No. 93, then in process of being subdivided into lots and concessions by order of the Department. Six weeks later, Crean, having ascertained that the land required was the parcel above mentioned, paid in the purchase money, and obtained a grant which issued on 25th November, 1884. As soon as the snow was gone next spring the owners put a force of 22 men at work, and sank a shaft to a depth of about 60 feet, but only a small quantity of ore was disclosed, and nothing further was done at the time.

Better success attended the efforts of the Dominion Mineral Company, which reopened the deposit in 1890 and worked it until 1894, during which time some 25,000 tons of ore were extracted. Some of the ore was exceedingly rich. Shipments were made averaging 8 per cent. nickel; one of 123 tons in 1893 contained 10 per cent. nickel and 3 per cent. copper. Large masses of ore have shown as much as 17.48 per cent. of nickel, due to the abundant dissemination of pentlandite, and again considerable quantities of chalcopyrite have been obtained carrying up to 18 per cent. copper and 2.5 per cent. nickel.

In several respects the Worthington mine is unique among the mines of Sudbury. It is very rocky, and contains compounds of nickel carrying high percentages of the metal, such as niccolite and gersdorffite, as well as a variety of other minerals in small proportions. The mine has passed into the hands of the Mond Nickel Company, and is now being worked by them. The property was at first called the Crean mine, after the purchaser from the Crown, but received its permanent name from James Worthington, manager of railway construction at the time the discovery was made, who was one of the directors and a large shareholder of the Dominion Mineral Company. The total production of ore to 31st December, 1915, was 117,794 tons. The average contents of the ore as shipped are nickel 3 per cent., copper 3.46 per cent.

McAllister or Lady Macdonald and No. 2 Mines

On 21st November, 1884, John H. Metcalf filed an application for the west half of lot 12 in the third concession of the township of McKim and the east half

of lot 1 in the third concession of the township of Snider, immediately adjoining on the west, accompanied by an affidavit by Thomas Frood that in the month of September previous he had examined these lands and that they were in a state of nature, etc. At that time the law did not make discovery of mineral a prerequisite for a purchase of land for mining purposes, and Frood's affidavit makes no claim of discovery. The presumption, however, is that Frood had found mineral on the land. A grant issued to Metcalf on 20th March, 1885. On the north part of the parcel in Snider, Metcalf and his associates did some development work. This was at first called the McAllister mine (from Metcalf's partner), but afterwards came to be known as the Lady Macdonald mine, from the fact that Lady Macdonald, wife of Sir John A. Macdonald, paid the property a visit in 1886. The deposit was purchased by the Canadian Copper Company, and it is termed by them No. 5 mine. It has never been extensively developed. From an open pit some 8,092 tons of fair ore were taken, of an average tenor of 2.84 per cent. nickel and 1.06 per cent. copper.

The parcel in McKim, afterwards known as No. 2 mine, or McArthur No. 2, proved to contain one of the most productive mines which the Canadian Copper Company, who purchased it, has yet possessed. It was not opened up until 1898, and was worked steadily for five years. When the great Creighton mine, with its rich and easily quarried ore, was beginning to meet the company's requirements, No. 2 was closed. It was again opened and worked in 1906 and 1907; closed in the last mentioned year; and re-opened in 1911, since which time it has been producing on a moderate scale without interruption. Up to 31st March, 1916, it had yielded an aggregate of 719,914 tons of ore. The ore of No. 2 is of good grade, and carries considerable rock. It averages 2.63 per cent. nickel and 1.79 per cent. copper.

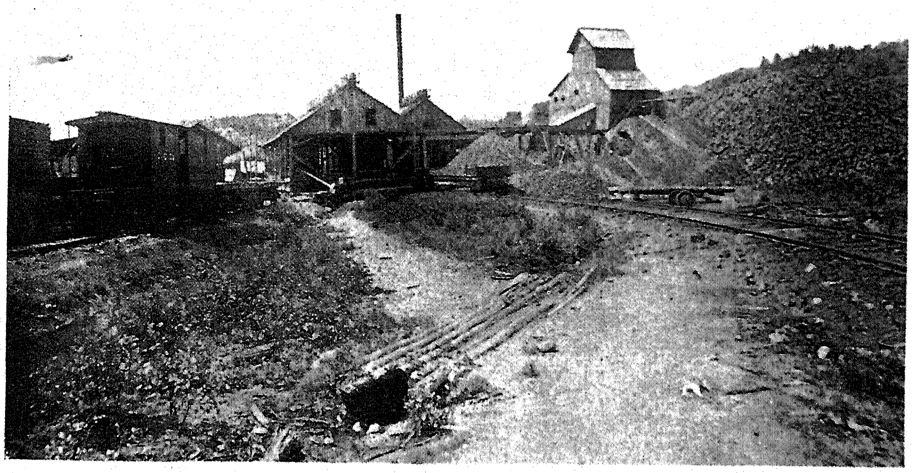
Howland Mine

A showing of copper ore was discovered by Francis C. Crean on the north half of lot 1 in the second concession of Drury in 1884, and Henry Totten applied for a grant on 27th May, 1885, filing Crean's affidavit in support. Patent issued to Henry Totten 11th March, 1886. A pit displays a "crushed conglomerate with greenstone boulders two or three feet through, enclosed in ore."[1] This is known as the Howland prospect or mine, and the ore gave an assay of 5.1 per cent. nickel and 2.1 per cent. copper. Some 1,724 tons of ore were mined from this deposit in 1916, of which 486 tons were purchased by the Mond Nickel Company.

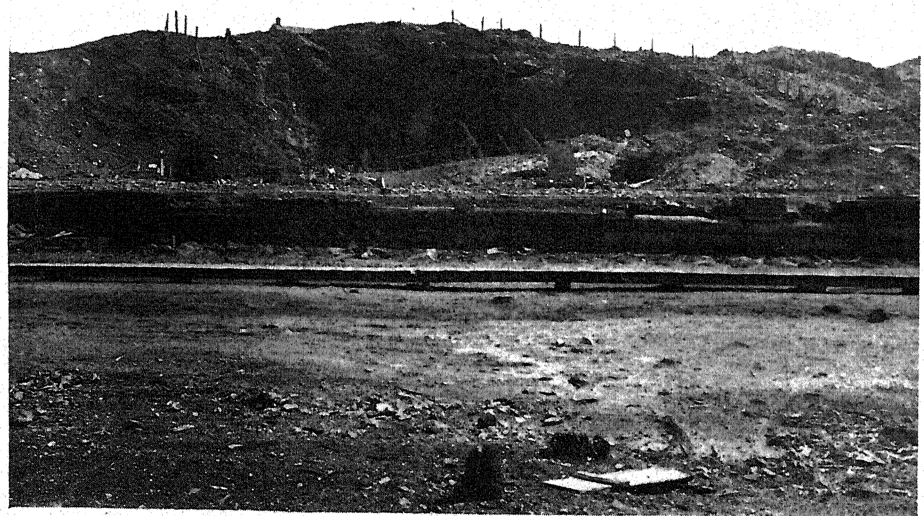
The Creighton Deposit Re-discovered

The success which had attended the efforts of the prospectors in 1884 naturally led to more extensive search in the following year, and in 1885 a number of important discoveries were made. Metcalf and McAllister were again on the lookout for copper properties, and Thomas Frood was associated with them as scout. The great Creighton deposit, whose influence on the magnetic needle had caused the aberrations noted by surveyor Salter and geologist Murray twenty-nine years before, was re-discovered, apparently by Henry Ranger. The latter states that after having finished the season of 1886 as prospector for Rinaldo McConnell, he set out on his own account and located the Creighton deposit that autumn, but

[1] The Nickel Industry, by A. P. Coleman, Mines Dept., Ottawa (1913), p. 46.



Copper Cliff mine, Copper Cliff, Sudbury area, Ontario, from a photograph published by the Canadian Geological Survey, about the year 1890.



Showing Copper Cliff mine on July 3rd, 1916. The mine has not been operated since 1905.

that he was forestalled in his application to the Department by others. Metcalf and McAllister had applied to the Department 10th July, 1885, more than a year before, for several lots in the townships of Denison, Creighton and Snider, including the north half of lot 10 in the first concession of the last-named township, the Creighton lot, but there is nothing in the Departmental record to show that any discovery had been made, beyond the presumption raised by the application itself. This presumption is weakened by the unusual delay in securing title. In 1885 Samuel J. Ritchie, president of the newly-organized Canadian Copper Company, obtained a transfer of the rights of Metcalf and McAllister in the lands they had applied for, and on 24th January, 1887, patent issued to the Canadian Copper Company. Mr. Ritchie desired to know the exact situation of the outcrop with regard to the survey lines, and sent J. W. Evans and Thomas Baycroft to locate it. After tracing up the lines they found the post which marked the junction point of the townships of Waters, Graham, Creighton and Snider standing right on the hill of the Creighton mine. The deposit itself lay a short distance to the north and east.

Until the building of the Algoma Eastern railway, there was no means of transporting ore from the Creighton mine to the company's smelting works at Copper Cliff. In 1900, however, it began to produce and in steadily increasing quantities. Up to 31st March, 1916, the shipments had amounted to 4,753,433 tons. As is well known, the ore is of high quality, being especially rich in nickel. The average so far has been 4.44 per cent. nickel and 1.56 per cent. copper. The ore body is freer from rock matter than that of any other important mine, about 70 per cent. of the ore being sulphides.

The Creighton mine has been pronounced, and no doubt with truth, to be the greatest nickel mine in the world. At the present time it is supplying the larger part of the ore smelted in the furnaces of the Canadian Copper Company, and as the nickel output of this company is much greater than that of any other concern, the Creighton mine is actually furnishing the bulk of the nickel being used by the world. Some years ago borings by the diamond drill revealed the presence of reserves of ore at depth estimated at 10 millions of tons. The first workings were by the open pit method, but the mine is now worked by shafts and levels in the usual way.

The Copper Cliff Mine

Another of Thomas Frood's discoveries in 1885 was the Copper Cliff mine, situated on the north half of lot 12 in the second concession of the township of McKim. Application was made for this parcel by J. H. Metcalf 29th May, 1885, and W. B. McAllister's affidavit was filed showing personal inspection by himself. Grant was made to Metcalf and McAllister 17th July, 1885. The Copper Cliff mine, so named from the steep, gossan-covered hill which marked the outcrop of the ore body, was the first property on which serious mining was done, in 1886. It was the first mine from which shipments of ore were made, and it provided the site for the erection of the first smelter, which was blown in 24th December, 1888. The modern town of Copper Cliff, with its extensive metallurgical plants, spacious company offices, hospital, schools, club house and residences for officials and workmen, has grown up around this pioneer opening. An electric street railway connects its well-paved streets with those of its neighbouring town, Sudbury.

The surface ore of the mine was rich in copper, running up to 15 and 20 per cent., hence it is not surprising that the first consignments to the Orford Copper Company's refining works at Capelton, Que., and Constable Hook, New Jersey, were regarded as copper ore only. It was while treating one of the early shipments from this mine in 1887, at Constable Hook, that the discovery was made that the ore carried an important percentage of nickel. Mining began in 1886, and continued until the mine was closed down in 1905, the ore from the Creighton replacing the product of the other mines in the company's operations. The ore body had diminished in size, but was not worked out when the lowest level was reached at a depth of 1,052 feet. In all, the mine has yielded 376,739 tons of ore, averaging 3.52 per cent. nickel and 5.13 per cent. copper. In carrying a higher proportion of copper than of nickel, it resembles the Crean Hill mine, but the ore is richer.

Mount Nickel Mine

Mount Nickel mine is situated on the south half of lot 5 in the second concession of the township of Blezard. The deposit was discovered in August, 1885, by James Stobie, another of the early and active prospectors, who transferred his right as discoverer to Martin L. Russell, and patent issued to the latter and Alexander Russell on 15th December, 1886. In 1899 the property was bought by the Great Lakes Copper Company, which opened it up by means of a shaft put down to a depth of about 165 feet, also by some drifting at the 75-foot level. The workings showed considerable ore, and a smelter was built to make high-grade matte without preliminary roasting, the process being one designed by Anton Graf, of Vienna. It did not succeed, and operations ceased in May, 1901. In 1911 considerable diamond drilling was done, and the ore body more closely defined. In 1915 the mine was leased by T. Travers, T. Smith and J. A. Holmes, who raised a quantity of ore and disposed of it to the Mond Nickel Company, the average contents being 2.4 per cent. nickel and 1.2 per cent. copper. This is one of the few developed mines not owned by one or other of the large operating companies.

The Stobie Mine

The Stobie mine, situated on the south half of lot 5 in the first concession of the township of Blezard, was also discovered in the same year. The discoverer was James Stobie, after whom the mine was named. On the 1st of September, Stobie and Rinaldo McConnell applied for the location, the former making affidavit that he had found thereon a deposit of copper pyrites, and that there were no indications of any previous discovery. A grant accordingly issued to Stobie and McConnell on 18th March, 1886. It was afterwards purchased by the Canadian Copper Company. The Stobie mine was opened in 1886, and continued in operation until 1901, during which time it produced 418,991 tons of ore. The workings were mainly by open cut. The ore, though not rich, consisted largely of massive sulphides, and hence was useful in mixing with more silicious ores. The average contents were nickel 2.05 per cent. and copper 1.53 per cent. The ore body is by no means worked out, but not being up to the Creighton standard in quality, is in the meantime being held as a reserve.

Crean Hill Mine

In 1885 was located the Crean Hill mine, south half lot 5 in the fifth concession of Denison township, so called after F. C. Crean, who applied for and obtained a grant in the name of his wife, Ellen Crean, 25th November, 1885. Crean's application was made on August 5th. There are no details as to the discovery among the papers in the Department, but doubtless Crean himself, who was early in the Sudbury field as a prospector, was the discoverer. Crean Hill[1] mine passed into the possession of the Canadian Copper Company, but was not opened up until 1905. The ore was useful for mixing with that of the Creighton mine, being quite silicious, and containing more copper than nickel, in this respect being the converse of the ore from the Creighton. Up to 31st March, 1916, 744,747 tons of ore were taken from the Crean Hill, the average tenor of which was 2.14 per cent. nickel and 2.91 per cent copper.

The Evans Mine

In this year also the Evans mine, south half lot 1 in the first concession of Snider, was discovered and taken up. The grantee was Samuel B. Eyre, who kept a boarding-house at Chapleau. His son, F. J. Eyre, is said to have been the discoverer.[2] The deposit was first called the Crean mine, but was afterwards named the Evans, after John D. Evans, who was the Canadian Copper Company's first engineer, and general manager from May, 1890, to June, 1893. It became the property of that company, and was worked from 1889 until the close of 1899. The ore was of good grade, containing 3.02 per cent. nickel and 2.73 per cent. copper. It produced 234,428 tons of ore. The mine was thought to have been bottomed, but it is now considered more than likely that the ore body was cut off by a fault.

The Blezard and Little Stobie Mines

The Blezard deposit, on the south half of lot 4 in the second concession of Blezard, though not granted until 9th March, 1888, appears to have been known as early as 1885, as on 16th September in the latter year George Morgan and James Craig applied to purchase. For some reason, not now apparent, this application was not followed up, and in February, 1888, Colbert Ducharme and Edward William Hillman, of Ottawa, made application, and received a grant on the above date. The Blezard mine was purchased by the Dominion Mineral Company, who opened it in 1889 and ceased working in 1893, during which time the production is given at about 100,000 tons of ore. The mine was worked chiefly by the open pit method. Two shafts were sunk, the deeper of which was about 150 feet. A smelter erected on the property converted the ore from this mine, and the Worthington deposit, owned by the same company, into low-grade matte. The ore is said to have carried about 4 per cent. nickel and 2 per cent. copper. After the Blezard ceased working, the smelter continued to operate mainly on Worthington ore until July, 1895. The buildings have since disappeared. The Mond Nickel Company now own the property and are at present prospecting it by the diamond drill.

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[1] There is no authority for the spelling "Krean" Hill.
[2] J. W. Evans, in Proceedings Can. Mg. Inst., Vol. VII, 1904, p. 497.

What is known as the Little Stobie mine, north half lot 6 in the first concession of Blezard, was discovered by James Stobie on 10th August of this year, and patented to George C. McKain 18th May, 1886. This mine was operated for a short time by the Mond Nickel Company, in 1902, 1,584 tons of ore having been taken out.

Three of the deposits discovered in 1885, namely, Copper Cliff, Stobie and Evans, were the chief sources of supply for the Canadian Copper Company's smelters during the first eleven years of that company's operations.

The Totten Prospect

The north half of lot 2 in the first concession of Drury was patented to Henry Totten 29th May, 1885. Francis C. Crean seems to have been the discoverer in this case also. A few hundred tons of ore were taken from the deposit a number of years ago for experimental purposes, but no serious mining has been done.

McConnell or Victoria Mine

In 1886, Henry Ranger, originally a wood ranger, was prospecting for minerals on behalf of Rinaldo McConnell. Though without previous instruction of any kind, Ranger developed keen prospecting instincts, and was looked upon as one of the best in his line. At this time the particular scene of his labours was the township of Denison. He tells us[1] that he found copper on lot 8 in the fourth concession, also on several lots in the immediate locality, and McConnell applied to the Department for the lands, namely the north halves of lots 8, 11 and 12 in the fourth concession, the north half of 1 and the south halves of 6, 8 and 9 in the fifth concession, in all 1,165 acres, 26th October, 1886. Patent was issued 25th January, 1887, to Emma McConnell, Alexander McIntyre and Joseph Riopelle, McConnell having assigned a one-half interest to the two latter. The property was developed to some extent by McConnell, and sold by him in 1899 to Dr. Ludwig Mond. This work and further development by the purchaser by means of the diamond-drill and otherwise, proved the presence of several bodies of nickel-copper ore, and particularly a valuable and persistent deposit on the north half of lot 8 in the fourth concession. Until a comparatively recent date, when other sources also began to be drawn on, this deposit furnished the bulk of the ore treated by the Mond Nickel Company. It is still being operated by that company, and shows the deepest workings of any mine in the Province, the lowest depth at the present time being about 2,600 feet. The ore shows no diminution in metallic contents resulting from depth. At first the property was called the McConnell mine, after the original grantee, but was renamed Victoria mine by the Mond Company.

Ore began to be drawn from the property in 1900, the total production to 31st December, 1915, being 619,612 tons. All of this but 8,225 tons came from Victoria No. 1. The average ore contains 1.62 per cent. nickel and 3.36 per cent. copper.

[1] Rep. Roy. Com. Min. Res. Ont. (1890), p. 425.

The Vermilion Mine

A notable find in the year 1887 was also by Henry Ranger who continued to prospect in his favorite field, the township of Denison. Here, Ranger states,[1] he found gold on several lots, and on 3rd September, gold and copper on lot 6 in the fourth concession, subsequently called the Vermilion mine, from the river of that name. On 13th September Robert John Tough applied for lots 5 and 6 in the fourth concession, and filed affidavits of Henry Ranger and Samuel McMartin showing no adverse claim. On 9th October, 1887, the patent issued to Mr. Tough. The papers show that Rinaldo McConnell had made an application for lot 6 in the fourth concession on 12th October, 1886, supported by affidavits of Wabumaki and Joseph Faille, but he subsequently withdrew his claim as regards lot 6 in the fourth concession and the southwest quarter of lot 6 in the fifth. In the files is also a letter dated 7th November, 1886, from Mr. S. J. Ritchie, president of the Canadian Copper Company, claiming the lands mentioned in McConnell's application by virtue of their having been included in an application made the year before by J. D. Evans, the company's engineer. Mr. Ritchie expresses the view that a company like his, making so large an outlay at Sudbury, amounting to hundreds of thousands of dollars, had a better claim than speculators, who only wished to sell to the company at an advanced price. Mr. Ritchie was given an opportunity to renew his protest when Tough's application was being considered by the Department, but apparently he failed to do so, and the grant issued to Tough.

The Vermilion mine is unique among the Sudbury deposits. It was at first regarded as a gold mine, and part of the property was worked as such, a small stamp mill having been erected to treat the ore. Wire gold was found freely distributed through the gossan and the upper portion of the deposit. In all, several thousand dollars' worth of gold has been recovered. Platinum in the form of sperrylite, or arsenide of platinum, was discovered in the gossan in October, 1885, by F. L. Sperry, chemist of the Canadian Copper Company, after whom the new mineral was named by the chemists Wells and Penfield, who studied it and determined its composition. The gossan was also found to contain palladium, and both platinum and palladium occur as well in the solid ore. Coleman states[2] that by assay, 198.28 tons of ore obtained in 1902 carried four ounces of silver, four ounces of palladium, one and one-half ounces of platinum and one-third of an ounce of gold per ton. The ore body is not a large one, as ore bodies go in the Sudbury district, but the nickel and copper contents are unusually high, running from two to four times as much as in other mines, and the precious metals contained enhance its value. In the case of the nickel, this is doubtless due to the mineral polydymite, which carries up to 42.35 per cent. nickel, and occurs abundantly. The mine is owned and worked by the Canadian Copper Company, who treat the ore separately from that of their other mines. Its production has been small, amounting at 31st March, 1916, to 4,014 tons, containing 6.64 per cent. nickel and 6.89 per cent. copper, together with other metals.

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[1] Rep. Roy. Com. Min. Res., Ont. (1890), p. 425.
[2] The Nickel Industry (1913), p. 45.

Tardy Recognition of Nickel in the Ore

Considering the importance which the nickel field of Sudbury has assumed, it seems strange that the element which made these ore deposits really valuable was not recognized until nearly four years after the first discoveries of ore were made. Until 1887 no one had any idea that the ore contained any other metal than copper. The ore body in the rock-cut which afterwards became the Murray mine, was broken into by the railway navvies late in 1883. In July of the next year Dr. A. R. C. Selwyn, then chief of the Canadian Geological Survey, visited the deposit[1] and took a sample of ore which was analysed by G. C. Hoffman, the Survey chemist. The latter's report thereon is found in the Survey's volume for 1885, page 19 M. The analysis showed the sample to contain 9.08 per cent. copper; 27.36 per cent. iron; 18.69 per cent. sulphur; 36.63 per cent. insoluble matter (gangue); mere traces of gold, and 2.187 ounces of silver per ton of 2,000 lbs. There is no mention of nickel, and it is not stated that any examination was made for this metal. In his report of 1887, Dr. Selwyn speaks of "the extraordinarily massive, cupriferous ore bodies in the vicinity of Sudbury"[2] which were being actively developed, but he says not a word about nickel. It is not until a year later, namely in 1888,[3] that the first mention is made in the reports of the Geological Survey of the occurrence of nickel in the Sudbury deposits, Dr. Selwyn stating that he had spent the whole of August of that year in studying the great mineral belt extending from Sault Ste. Marie to Sudbury, in which were situated "the newly discovered nickel-copper and gold-bearing deposits in the vicinity of the latter place."[4]

How the Nickel was Identified

What the assayers and geologists for nearly four years failed to recognize was discovered by the smelters of the ore. The Copper Cliff mine was opened up in 1886, and in 1887 a shipment of some 1,200 tons of the ore was made to the Orford Copper Company's works at Constable Hook, New Jersey, to be smelted. In the manipulation of the ore difficulties were encountered, and on investigation these were found to be due to that "spirit of the mine," which the old German miners blamed for inciting their copper ores to bad behaviour—in other words, to the presence of nickel. S. J. Ritchie tells us[5] that when the chemist of the Orford Company was analyzing the furnace products of these ores, he found a metal with which he was not familiar, and which after numerous tests he found to be nickel. Mr. Ritchie adds that he himself happened to be in the laboratory when the discovery was made, along with Robert M. Thompson, the president of the company and owner of the works. In narrating the incident Mr. Ritchie says:[6]

> The discovery of this nickel in these ores by the chemist of the Orford Company was unexpected news to both Thompson and myself. We had no suspicion that they were anything but copper ores This discovery changed the whole situation. We found we had a great nickel deposit instead of a great copper deposit, or to be more correct, we had a great nickel and copper deposit.

[1] Nickel and Copper Deposits of the Sudbury Mining District, by Alfred Ernest Barlow, Geol. Sur. Can. (reprint), 1907, p. 24. [2] Geol. Sur. Can., 1887-8, Pt. I, p. 2-A. [3] Ibid, p. 58-A. [4] It is only fair to say that the earliest specimens of nickel ore in Ontario, first at the Wallace location, and afterwards at what is now the Creighton mine, were found by Alexander Murray and assayed by Sterry Hunt, both of whom were members of the Geological Survey. But the recollection of these discoveries seems to have been lost. [5] Ont. Bur. of Min., Vol. XIV, 1905, Pt. III, p. 170. [6] Ibid, p. 170.

It does not appear that the knowledge that the Sudbury ores contained nickel as well as copper had much effect in stimulating the discovery of new deposits. This was probably due to the majority of the outcropping ore bodies having already been found and taken up.

The Search for Gold

The discovery of remarkably rich gold ore at the Vermilion mine in 1887 before nickel was known to be a constituent of the ore bodies, gave rise to the hope that the region would prove to be valuable for gold as well as for copper. Dr. Selwyn regarded the general geological features of the region as corresponding very closely with those observed around Lake of the Woods,[1] where also a number of gold-bearing veins had been discovered, and expressed the opinion that the most important gold district in Ontario was in the vicinity of Sudbury.[2] A closer study of both areas has ere this dispelled the idea of similarity in their geological conditions; but it is certain that during 1887 and for several years afterwards, prospectors were as keen in searching for gold as for deposits of chalcopyrite and pyrrhotite, whose nickel contents were to prove of incomparably greater value than all the gold up to that time or even yet recovered in Ontario. An attempt was made by the Creighton Gold Mining Company to work for gold parts of lots 11 in the fifth and sixth concessions of the township of Creighton, where gold had been found by J. R. Gordon in 1889. Considerable development work was done, and a mill operated for a short time in 1893, but the venture did not have lasting success. The only returns of any account which have resulted from gold mining in the nickel area were those obtained at the Vermilion mine already mentioned. To this should be added the gold recovered in refining the nickel-copper mattes.

A Find in Falconbridge

The first discovery of nickel ore in what is now the township of Falconbridge, then called timber berth No. 48, was made in November, 1887, by Richard S. Donally, a fire ranger and timber scaler in the employ of the Emery Lumber Company, who held the timber cutting rights on the berth. Owing to the objections of the company, who feared an influx of prospectors, and consequent danger to their timber from fire, Mr. Donally did not open up the deposit, or even apply to the government for the land, until 1890, when he found some other employees of the company had located his find and were attempting to obtain a grant. Patent issued 28th October, 1891, to himself, John Paterson, and the Emery Lumber Company. The township not then having been subdivided, Donally's location was surveyed as M 2.

Robinson, McIntyre and Sheppard Mines

Michael Corrigan discovered ore on the west half of lot 12 in the second concession of Denison on 15th October, 1887, and this half lot was patented to him and Hiram Robinson 5th April, 1888. The showing is in the northwest corner of the lot, but little mining has been done upon it This prospect is known as the Robinson. The McIntyre location, lot 11 in the third concession of Denison, was patented to David L. Lockerby, 3rd January, 1888. A pit shows ore and norite enclosing "numerous rounded masses of country rock."[3]

[1] Geol. Sur Can., 1887-8, p 59-A.
[2] Rep. Roy. Com. Min. Res Ont (1890), p. 66.
[3] Coleman, The Nickel Industry, p. 46.

What has been called the Sheppard, and also the Beatrice or Davis mine, on the south half of lot 1 in the third concession of Blezard, was applied for by Oliver B. Sheppard 16th December, 1889, and was patented to Thomas Henry Sheppard 12th June, 1890. John H. Babcock seems to have known or suspected the presence of mineral some three years earlier, for he had done a little work on the ground, but did not file an application with the Department until 24th January, 1890. The grant to Sheppard was conditional upon his paying Babcock the fair value of the work the latter had done. A shaft was sunk in 1892 to a depth of 110 feet, and a couple of drifts run. About 125 tons of ore were taken out, of which the nickel contents averaged 5.75 per cent., this high proportion being considered due to the presence of polydymite. Copper was low, about .35 per cent. Work was suspended in April, 1893, and has not since been resumed. The showing of gossan on this property is considerable.

Chicago or Inez Mine

In 1889 the Chicago, also called the Travers or Inez mine, was located on the 20th June by Benjamin Boyer, who was prospecting for James B. Miller of Sault Ste. Marie. The property is situated about the centre of lot 3 in the fifth concession of the township of Drury, and patent issued to Sophronia E. Miller 12th July, 1889. In 1890 it was purchased by the Drury Nickel Company, which began working it the following year. A smelter was erected in 1892, and the ore was reduced to matte in a water-jacketed furnace. About 3,500 tons of ore, taken mostly from open cuts, were thus treated. The matte was sent to the Emmens Metal Company, of Youngwood, Penn., for refining. In the same year the mine was closed down; re-opened, but again closed in 1893. It is stated that the Emmens company's process of refining was unsuccessful, and that the matte was in the end refined by Joseph Wharton, the nickel refiner of Philadelphia. The company having undergone reorganization as the Trill Mining & Manufacturing Company, mining was commenced again in 1896, the name of the property having been changed to the Inez mine. After operating until August, 1897, work was discontinued, and has not since been resumed. The Drury Nickel Company went into liquidation, and the mine became the property of Mr. Wharton. On the amalgamation of his interests with those of the International Nickel Company, it passed into the hands of the Canadian Copper Company.

In 1890 prospecting was inactive, or at any rate unsuccessful, for no important deposits seem to have been located this year.

The Gersdorffite Location

On the 29th November, 1890, Daniel O'Connor applied for lot 12 in the third concession of Denison. During the winter months following O'Connor built a shanty and sank some test pits on the land, and obtained a grant 1st May, 1891. There is an outcrop of ore in the southeast part of the lot, on which some specimens of the rich nickel mineral gersdorffite were found—hence the name, Gersdorffite mine or location. The deposit has not been worked in a commercial way.

The Garson Mine

Better success was had in 1891. While prospecting in the midst of a tract of standing pine, John Thomas Cryderman discovered a large showing of gossan

on the south portions of lots 4 and 5 in the third concession of the township of Garson. The discovery was made on 30th April, 1891, and on 2nd June the following year, Cryderman and his partner William Mayhew applied for the location. Desirous of protecting the pine timber from the danger of fire, the Department for a time declined to sell, but subsequently, on 28th January, 1895, granted a lease to William Mayhew and others, and patents issued for the separate parcels in 1897. The mine, which was at first known as the Cryderman, but afterwards as the Garson mine, passed into the possession of the Mond Nickel Company, and proved to contain a large tonnage of good ore. Considerable diamond drilling was done in 1905 to locate the ore bodies, and shipments to the company's smelter at Victoria Mines began in 1908. Raising of the ore has continued without interruption since that time, and in yearly increasing quantities. Up to 31st December, 1915, the total quantity mined was 872,179 tons. The average contents were 2.4 per cent. nickel and 1.7 per cent. copper.

Sultana and Trillabelle Properties

The Sultana property was taken up in 1891 by Sophronia E. Miller, wife of James B. Miller, the grant issuing 19th December, 1891. The deposit is situated on the south half of lot 8 and the southwest quarter of lot 7 in the first concession of the township of Trill, and the discoverer was Benjamin Boyer, who made the find in the summer of that year. Several test pits have been sunk, and a shaft put down to a depth of 110 or 120 feet. The dump from the latter shows considerable ore, mainly pyrrhotite, but the property has never been extensively operated. Boyer also discovered at the same time a body of nickel ore half a mile east of the Sultana mine on lots 6 and 7 in the sixth concession of Drury and first concession of Trill, known as the Miller claims or Sultana East, on which drilling is now going on.

Ralph Gillespie, a prospector employed by William Oscar Washburn, discovered nickel-copper ore in September, 1891, on the northwest quarter of lot 10, and the northeast quarter of lot 11, in the third concession of the township of Trill, and Washburn obtained a mining lease of the lands 28th October, 1892. This lease was converted into a patent to George Washington Mann 17th July, 1894. Washburn's application was contested on behalf of Sophronia E. Miller, on the strength of discoveries made in the same locality by Alexander McKay in August, 1892, but the dispute was decided in Washburn's favour. The property is known as the Trillabelle or Gillespie. Mrs. Miller's application was allowed for the north half of the southeast quarter, and the south half of the northeast quarter of the adjoining lot 11 in the fourth concession. The latter property was transferred to the Great Lakes Copper Company, and the lease to Mrs. Miller was merged into a patent to that company 27th May, 1902.

Cameron Mine

What is known as the Cameron mine on lot 7 in the first concession of Blezard, was discovered in August, 1892, by Robert McBride, who applied to purchase 3rd September following, and patent issued to him 2nd November, 1895. McBride was a captain at the Blezard mine a short distance away, operated by the Dominion

Mineral Company, and associated with him was Ian Cameron, then the company's manager, after whom the mine or prospect was named. The company undertook development work on the Cameron property, put down a shaft to a depth of 65 feet, and ran a drift about 66 feet long. On 2nd November, 1895, Mr. Cameron writes[1] that they had found ore of good grade, and if only they could get enough of it, they would be able to make a mine of the property. The Dominion Mineral Company, however, went out of business in 1895, and the Cameron mine has remained idle ever since.

Cryderman Claims in Falconbridge

In the township of Falconbridge, on lot 7 in the fifth concession, south of location M 2, where Richard S. Donally had discovered ore in 1887, Albert Harvey made a similar find on 3rd May, 1892. Like Donally, he was deterred from asserting his claim by the opposition of the owners of the timber, who feared the introduction of fire, and by the consequent refusal of the Department to sell the land. In the meantime, a dispute arose between himself and John T. Cryderman, who was prospecting in this neighbourhood in 1898. The dispute was decided by the Department in Harvey's favour, but he never took out a patent, and the claims were again staked in May, 1911, by Newton Cryderman, in pursuance of whose application grants were issued for two parcels of 46½ acres each to Charles McCrea, Newton Cryderman, Frank Rioux and Louis Laforest 29th October, 1915.

The Kirkwood Mine

On 4th June, 1892, William McVittie and George Jackson discovered the Kirkwood mine, south half lot 8 in the third concession of Garson, and a mining lease was applied for by their partner Alexander Mennie. Standing pine on the lands delayed the issue of the lease until 31st August, 1898. The property was leased by the owners to T. M. Kirkwood, who did a large amount of stripping, sunk a couple of shafts and made preparations to erect a smelter. The Canadian Copper Company bought out Kirkwood's interest, and allowed the mine to lie unworked for seven or eight years, when they surrendered the lease. The buildings erected by Mr. Kirkwood were burned down in 1898. Three years ago the owners leased the property on a royalty basis to the Mond Nickel Company, who extracted ore to the extent of 71,208 tons. On 1st January, 1916, the company purchased the mine outright, but closed it down with the view of equipping it with heavier machinery. It has not yet been re-opened. The average contents of the ore were, nickel 3.19 per cent., copper 1.55 per cent.

Gertrude Mine

The Gertrude mine is on the south parts of lots 3, 4 and 5 in the first concession of the township of Creighton, in the area where surveyor John McAree, who laid out the township in the year 1884, noted local magnetic attraction, and about two miles west of the great Creighton deposit, whose influence so disturbed the compasses of Salter and Murray in 1856. William McVittie and George Jackson located the Gertrude deposit in October, 1892, and their associate

[1] Letter on file Dept. Lands, Forests and Mines.

Alexander Mennie obtained a mining lease of the lands in December of that year. Subsequently, on 25th February, 1899, the lands were patented to Mennie.

The mine was purchased in 1899 by the Lake Superior Power Company, who at once set about developing it. Two shafts were sunk, one 120 feet deep and the other 80 feet, and the company's railway, the Algoma Eastern, was built from Sudbury to the mine. The primary object the company had in view was to produce ferro-nickel or nickel pig iron, after a process devised by E. A. Sjostedt, the company's chemist, to operate which a plant had been put up at Sault Ste. Marie. The process was also designed to utilize the sulphurous gases obtained in treating the ore, in the manufacture of sulphite pulp. The Gertrude ore was considered to be specially suited for ferro-nickel because of its high content of nickel and low proportion of copper, the latter being regarded as detrimental to the quality of the product. Nickel in the ore ran up to 6 per cent., as against less than 1 per cent. copper. However, as the body was opened up, the copper contents increased, and the process did not produce the results hoped for. In 1902 a smelter was erected, and the ore made into low grade matte. Ore was brought from the Elsie mine, also owned by the company, to the roast yards at the Gertrude, and the smelter ran from June to October, 1902. The company's collapse in 1903 brought all work to a close, and the matte on hand at the time remained unsold for several years. The mine was bought by the British America Nickel Corporation, but has not yet been re-opened. About 18,000 tons of ore were raised during the period of its operation. Over 13,000 feet of diamond-drilling was done on the Gertrude, and over half a million tons of ore proven.

Tam O'Shanter and North Star

The Tam O'Shanter property consists of the northwest part of lot 5 and the north half of lot 6 in the third concession of Snider. Thomas Baycroft discovered nickel ore on these lands 2nd September, 1893, and they were leased for mining purposes to Catherine Baycroft his wife, on 31st October, 1895. The title was subsequently acquired by the Canadian Copper Company, who also bought the southeast quarter of lot 6 on 30th September, 1913. There are some small outcrops on these lands, but no mining has been done upon them.

The North Star mine on the south part of lot 9 in the third concession of Snider, did not pass out of the possession of the Crown until 1898. It is in the neighbourhood of a number of older mines, and has sometimes been referred to as a deposit which the early prospectors overlooked. In September of that year Aeneas McCharles applied to the Department for the south half of the southwest quarter of lot 9, the part on which the mine is situated, showing discovery of nickel ore by himself on 17th September, 1898. He filed assignment from Geo. Cobb and Alexander McDonald for adjoining parcels, and a lease of the property issued to his nominee, Mary Potcher, 13th September, 1899. On the departmental files was an old application made in October, 1893, by D. P. Shuler, supported by affidavits from Edward Townsend and James McVeigh. An attempt was made to revive this application while that of McCharles was pending, but the Department took the view that as an opportunity to obtain title had been given but not taken advantage of, the application had lapsed and was not a bar to a grant

to McCharles. A still earlier claim had been put forward by the Canadian Copper Company in 1890, on affidavits made by Thomas Baycroft and John Walter Evans, but this, too, had never been followed up.

In 1903 the North Star mine was taken over by the Mond Nickel Company, who opened it up and took the ore to Victoria mines for treatment. The ore carried on an average 2.1 per cent. nickel and 0.8 per cent. copper. Coleman remarks on the similarity of the ore of the North Star and Gertrude mines to that of the Creighton, on the opposite flanks of which great deposit these smaller bodies are situated,[1] the ore in all three being high in nickel and low in copper. The mine was closed in 1904, but re-opened in 1912. In 1915, at which time the workings comprised a shaft 375 feet deep and three levels, the returns did not warrant further expenditure, consequently the property was abandoned, the machinery removed and the buildings torn down. The total production of ore from this small deposit was 54,274 tons.

More Finds in Falconbridge

On the strength of discoveries made by John T. Cryderman 8th November, 1898, a grant was issued to Charles Edward Ritchie of the north half of the north half of lot 7 in the fourth concession of Falconbridge and the south 51½ acres of lot 7 in the fifth concession, to Harry Russell Leyden of the north-west quarter of the south half of lot 7 in the fourth concession, and to John Moodie of the whole of lot 8 in the fourth concession, the date of the grant in each case being 21st November, 1900. This last mentioned group of properties is now owned by the British America Nickel Corporation, and diamond-drilling has proven the existence upon them of over a million tons of nickel ore. Strictly speaking, they should probably be regarded as situated on the eastern range.

From the Garson mine easterly to the properties in Falconbridge referred to above, the surface is composed of sand and gravel, and the actual course of the norite contact is hidden from view. In places the drift overlies the rock to a depth of 50 to 130 feet, yet during the present year (1916) a considerable deposit of nickel ore has been located by diamond drilling. A syndicate from Minneapolis consisting of E. J. Longyear and others, who have had long experience in searching for ore bodies by the drill in the iron ranges south of Lake Superior, thought well of the chances of finding ore in Falconbridge, and after studying the ground, set four drills at work. They succeeded in locating ore over a length of 8,000 feet in the fourth and fifth concessions. The work of drilling is still incomplete, but the core sections show the deposits, which dip steeply, to have a width of 10 up to 150 feet. No estimate is possible of the total quantity of ore the deposits contain, since no borings have yet been made to determine the depth, but enough is known to warrant the statement that the discovery will prove of importance. It is undoubtedly the largest find of ore that has been made on the nickel range since the large bodies were located on the Frood, Murray and Creighton mines some years ago, and more recently at the Levack. The diamond drill has abundantly proved its value in the exploration of underground deposits in the nickel region.

[1] The Nickel Industry, p. 60.

The Eastern Range

The find on M 2 (Falconbridge township) in 1887 does not seem to have attracted much attention to that neighbourhood, the distance from the nearest find then known on the main range (Blezard mine) being about 12 miles, and the district, except for lumbering roads, being devoid of means of communication. Notwithstanding, the prospector was abroad, and in 1888, the year following the discovery on M 2, evidence was forthcoming which showed that the right conditions for the occurrence of nickel existed even farther from the deposits in the known or Sudbury area.

Locations W 1, W 2, W 3

An Indian travelling through the woods was intelligent enough to recognize indications of nickel ore on the southeastern bank of Clear lake in the region west of lake Wanapitei, now included in the township of Capreol. Rinaldo McConnell investigated the find, and purchased the Indian's rights. He had the showings surveyed as mining location W 1, and two other finds near by made by himself, as W 2 and W 3. The grant for these locations issued to McConnell, seven-eighths interest, and John B. Hall one-eighth interest, 21st October, 1889. This was the first discovery on what may be called the eastern range, namely, the stretch from the locations in Falconbridge north to the Whistle mine.

Coleman describes the nickel showings as follows[1]:—

> Across the northeast expansion (of Blue lake) a small outcrop of ore occurs . . . in location W 1. From this point the edge of the norite runs northwest to the eastern shore of Clear lake, in W 2 and W 3, where there are strippings and small pits showing ore, mostly close to the water's edge, but sometimes 100 or 150 yards up the hillside. . . . The lake basin was evidently formed by the weathering out of the basic norite with its fringe of ore.

No actual mining has been done on these locations, which along with others in the vicinity are now owned by the British America Nickel Corporation. The previous owners, the Dominion Nickel Copper Company, did some drilling, and located a large quantity of ore, in one place 800 feet thick.

The finding of deposits in this locality of the same type as those of Sudbury, and under similar geological conditions, clearly indicated the possibility of other discoveries of like character, and the hint thus given was soon followed up. In 1889 Edgar J. Jarvis applied for and obtained a patent of location W 7, which lies between Selwyn and Skinner lakes, about three miles north of Clear lake.

Nickel on Blue and Pyrrhotite Lakes

The following year, 1890, the Sudbury field proper having by that time been fairly well gone over, and most of the important outcrops now known having been discovered and taken up, prospectors found their way to the eastern range, naturally examining first the neighbourhood of the finds already made. Locations F 5, F 6, F 7 and F 8 were taken up on discoveries made in June, 1890, by Robert Woods, John Watson and Chas. E. Fitton, O.L.S. They are situated southeast of Blue lake on the north and east sides of Moose lake, or as Coleman re-christens it, Pyrrhotite lake. That author describes[2] the eastern shore of this lake as being

[1] The Nickel Industry, p. 86

[2] Ibid, p. 85.

almost entirely covered with gossan, a number of large test pits, as well as two or three small shafts, showing sulphides, mainly pyrrhotite. He adds:[1]

This dipping of the gossan and ore into the lake suggest that there may be considerable deposits under its bed, especially since very little norite can be seen above or mingled with the ore in the pits. . . . Not far to the south the eruptive has a width of about a mile and a quarter, and one would not expect a very large body of ore to segregate from so moderate a thickness of magma; nevertheless the gossan and ore at Pyrrhotite lake extend for 1,200 feet, following the shore, and for 760 feet in a straight line, with a breadth in places of 200 feet, so that surface indications are favourable, and the ore is unusually coarse-grained and rich.

W D 1 on the east shore of Blue lake and W D 4 within the limits of what may be described as lot 10 in the 3rd concession of Maclennan, were patented in October, 1890, to John K. Leslie and George S. Macdonald. According to Coleman, the former location shows norite spotted with gossan, but displays no large body of ore. W D 1 has been acquired by the British America Nickel Corporation, Limited, by whom it is known as the Victor mine. Drilling by them disclosed considerable ore of good grade. The same description applies to W D 6, which adjoins W D 4 on the northwest, W D 3, immediately northwest of W D 4, and F 8, which lies west of the latter. W D 6, along with W D 7 and W D 8, were located by W. B. Poulton in May, 1891, and were subsequently leased by the Crown to Edgar J. Jarvis. W 5 and W 6, west and north respectively of Clear lake, were applied for by James F. Whitson in November, 1890, and patented to him in May, 1891.

Clear and Ella Lakes

Following up the contact in a northwesterly direction from Clear lake, ore has been found on W R 11, W R 10 and W R 9, and at the southwestern corner of W R 2. All these locations lie on the eastern margin of Ella lake, and the occurrence of the ore close to the water's edge here as well as at Moose or Pyrrhotite and Clear lakes, has led prospectors recently to stake out mining claims on the beds of these lakes, the indications being that the deposits extend under the water. Waddell lake lies north of Ella lake, and lake Selwyn north of Waddell. From Ella lake northward to the Whistle mine in lots 6 in the fourth and fifth concessions of the township of Norman, a line of mining locations occupies the eastern shores of Waddell and Selwyn lakes, but the position of the contact is not very clear, and nothing of importance has yet been found upon them. It may be noted that it is characteristic of the entire chain of lakes on the eastern range that their longer axes are northwest and southeast parallel to the line of contact between the norite and the greenstone, which, for the most part, is close to the eastern shores of the lakes.

A Showing in Maclennan

Prospecting continued on the eastern range during the years 1891 and 1892, and most of the lands taken up from the Crown were acquired before the end of the latter year. Later prospecting, however, has not been wholly unrewarded. For two miles or more north of M 2 in Falconbridge a heavy deposit of gravel conceals the rock formations, but on the northwest quarter of the north half of lot 8 in the second concession of Maclennan, Frank Dennie discovered nickel on 10th

[1] The Nickel Industry, p 86.

April, 1902, and a mining lease was issued to him 6th August, 1908. On 16th November, 1907, a discovery was made by Abraham G. Bowland, on the southeast quarter of the north half of the same lot. The claim was transferred to the Canadian Copper Company and patent issued to the latter 21st December, 1909.

There has been little development work done on the eastern range, one reason being that railway facilities until lately were wanting, so that operations were necessarily expensive. This difficulty has been removed by the construction of the Canadian Northern Ontario railway, which crosses the range on its way northwestward from North Bay and runs parallel to a considerable portion of the range at a distance of a mile or more to the west. A spur of the same line connects Nickelton Junction with the Whistle mine, so that transportation conditions can now be said to be good. A number of the most promising properties on the eastern range were acquired from their owners by the Dominion Nickel-Copper Company, which in turn parted with them to the British America Nickel Corporation, with whom their present ownership rests.

The Northern Range

The northern range runs westward along the norite contact from the Whistle mine in the township of Norman in the east to lot 5 in the second concession in the township of Wisner, where it bifurcates. A string of mining locations follows the more northerly band of the norite to the Ross mine or W R 5, and another the contact of the southerly or main norite formation to lot 2 in the sixth concession of the township of Morgan. From this point the contact runs in a southwesterly direction through the townships of Levack, Dowling, Cascaden and Trill to the Sultana mine, which may be regarded as the most westerly body known on the main or southern range.

The Levack Mine

In the autumn of 1887 James Stobie undertook a careful examination of the rock cuttings and gravel pits on that part of the Canadian Pacific railway lying between the stations of Larchwood and Cartier. Near Windy lake, and also in the township of Levack, he found some boulders containing ore of the Sudbury type, but snow fell before he could locate ore in place. Two years later he resumed his search and located the outcrop on the south part of lot 7 and lot 6 in the second concession, also on lot 2 in the fourth concession. During the year intervening, the deposit on the north half of lot 6 had been found by a couple of Indians on behalf of Rinaldo McConnell, who on 30th November, 1888, applied to purchase. Patent for this parcel issued to McConnell 30th October, 1889, and for the south three-quarters of 7 to James Stobie, 4th November of the same year. The Levack mine, as it came to be called, was the first deposit located on the northern range. The discovery was made before any clear idea could have existed as to the number or arrangement of the "ranges," and was the result of an appreciation of the relationships between the norite contact and possible ore bodies. The property was held for a long time by the owners, James Stobie, Robert J. Tough, and Rinaldo McConnell, but was eventually sold by them to the Mond Nickel Company. In the course of diamond drilling the latter found a large body of ore separated from the out-cropping by rock and beneath the marshy ground adjoining.

Operations at the Levack mine were begun in 1913, a spur from the Canadian Pacific railway was built to the property, and in 1914 and 1915, 48,467 tons of ore were extracted, and conveyed to the smelter at Coniston for treatment. The ore averaged 3.2 per cent. nickel and 1.5 per cent. copper.

W R 5 or Ross Mine

The second discovery on the northern range seems to have been that of the Ross deposit, or W R 5, in 1890, where the norite offset from the main formation terminates on lot 6 in the third concession of what is now the township of Foy. The discoverer in this case was an Indian named Winge-kissinaw, who disposed of his find to Thomas B. Ross, and a grant from the Crown issued to the latter 23rd May, 1891.

Some exploration of the northern range went on in 1891 and 1892 concurrently with the exploration of the eastern area, but the larger number of the mining locations were taken up after the discovery of the Whistle mine, in 1897, that event, no doubt, reviving the interest of the public, and especially of the prospectors, in the nickel resources of this part of the region.

The Whistle and Wildcat Mines

At the extreme eastern end of the northern range and on the north part of lot 6 in the fourth and the south part of lot 6 in the fifth concession of the township of Norman is the Whistle mine. It is so-called after the discoverer, Isaac Whistle, who along with Arthur Belfeuille found here on 24th July, 1897, a hillside covered with gossan, one-half mile long from the southeast to the northwest, and 250 yards wide at the widest part. Whistle and Belfeuille transferred to Emma McConnell, wife of Rinaldo McConnell, to whom a patent issued 30th July, 1900. The latter transferred to the Dominion Nickel-Copper Company, who sold to the British-America Nickel Corporation, the present owners.

Beginning in 1910 the Whistle mine has been systematically tested by means of the diamond drill, shaft, pits, etc. A tunnel run into the hillside half way up, cut into a body of ore for 432 feet, and in a drill hole in the swamp below the hill, ore was found at a depth of 893 feet. The only ore actually produced so far is several thousand tons, which was taken out in driving the tunnel above mentioned, but the drill showed the Whistle to contain at least 1,300,000 tons of ore. The extensive gossan showing proved deceptive, resting on little ore, most of that which was found being in other parts of the property. It is said, too, that magnetic readings proved of little assistance in locating the ore shoots. A spur was built by the Dominion Nickel-Copper Company connecting the mine with the Canadian Northern railway three and one-half miles away, and connection has been made with the Wahnapitae Power Company's transmission line to obtain a supply of electric power. The ore is low in copper, and of medium grade as to nickel. An analysis given by Coleman shows .10 per cent. of the former and 2.76 per cent. of the latter. It was at one time proposed by the Dominion Nickel-Copper Company to establish roast-yards and a smelting plant at or near the mine for the treatment of the ore, and some 2,000 acres of land in Norman were purchased from the government with this end in view. But on the finding of unexpectedly large reserves in the Murray mine, the company's successors, the British America Nickel Corporation, decided to change the location of the smelter to the latter property.

What is doubtless an extension of the main gossan area of the Whistle, shows on the southwest quarter of the north half of lot 5 in the fourth concession of Norman, the outcrop here receiving the name of the Wildcat mine.

Westward of the Whistle

Westward from the Whistle to the crossing of the Vermilion river—a distance of about three miles—are a number of claims in the fourth concession of Norman, but the contact for the most part is buried under deposits of drift, and though some gossan and mixed ore have been found, no body of consequence has yet been located.

The same condition prevails in the adjoining township to the west, Wisner, for three miles or more, although prospectors have taken up claims in the third and fourth concessions on the assumption that the contact runs in a southwesterly and then westerly direction as far as Joe lake, half way across the township. Locations W R 14, immediately north of Joe lake, and W D 16, adjoining to the west, show much gossan, and in the latter location considerable ore has been disclosed in test pits and diamond drill holes.

Proceeding westward, gossan and ore are found on W R 13 and also on W D 15. Across the boundary line in Bowell township, ore outcrops on W D 13, where there is a promising show, with much gossan, on the face of a hill on which some stripping has been done. The ore apparently dips under the adjoining swamp. W D 208 shows ore; so does W D 210, where it occurs on a flat.

The Ross Mine Offset

At this point a smaller band of norite diverges westerly and northwesterly for about six miles, ending at the so-called Ross mine. What may be called the main contact continues southwesterly to the southwest corner of Bowell township and beyond, as already described. Tracing first the course of the smaller band, which varies in width from 20 to 500 feet, it is found that several locations round a small body of water known as Nickel lake show gossan and ore. The lake bed itself has also been staked out. On W D 150, at the southwest end of the lake, some 15 holes were put down with the diamond drill, proving a considerable body of ore, and a smaller quantity was located on W D 151, at the northwest corner of the lake. W D 155, adjoining W D 150 to the east, also contained ore. To the west of Nickel lake, ore is indicated on W D 228, but the norite contracts in width and does not appear to contain anything more of importance except perhaps at the termination of the band, where there is a body of ore on W R 5, otherwise known as the Ross mine. An assay of the ore here gave 2.75 per cent. nickel.

Ore and a Barren Stretch on Main Contact

The main contact from the point of bifurcation shows ore at several places as it runs southwesterly through the township of Bowell. W D 37 and W D 238 display gossan and some mixed ore; on W D 231 a little work has disclosed ore about 15 feet wide and 50 feet long; while test pits prove ore to be present on W D 241 and W D 251. Beyond a small showing of gossan in the northeast corner of lot 1 in the sixth concession of Morgan, the contact in its course in a general southwesterly direction across the full width of this township to the point where

it crosses the boundary line on lot 12 in the fourth concession, seems quite barren of ore. The rocks throughout are fairly well exposed, but the band of intrusive is unusually narrow, varying from three-quarters of a mile on the east side of the township to a mile and a half on the west, and is acid throughout, the basic edge which marks it in other areas being absent. This is Coleman's explanation of the lack of ore in this stretch of the northern contact.[1] Entering Levack township, the eruptive band expands in width, and speedily resumes its normal character, some gossan and ore marking the contact between the norite and the granite on the north part of lot 1 in the fourth concession.

Big Levack and Strathcona

To the west, on the north parts of lots 2 and 3 respectively, are the properties known as the Big Levack and Strathcona mines. James Stobie discovered the former outcrop in 1889, and obtained patent therefor on the 15th November of that year. There is on the Big Levack a large exposure of ore and gossan, but according to Coleman, the ore body is very thin, not sufficient in places to conceal the underlying surface of granite. "It appears," he states,[2] "that most of the norite and ore has been weathered away, leaving only what was protected in the hollows of the harder rock beneath. It may be, however, that the swamp at the foot of the gentle slope hides the thicker parts of the ore body."

On the Strathcona property the conditions are similar, the ore being widely, but irregularly, spread. Numerous test pits have been sunk, also two shafts. No. 1 shaft is 45 feet deep, showing 8 feet of barren cap rock, 25 feet mixed ore and 12 feet of solid pyrrhotite. The latter continued, as shown by a drill hole, at least 10 feet further down. Shaft No. 2 is 30 feet deep, 6 feet being in cap rock and 24 feet in solid pyrrhotite. From data furnished by the late E. A. Sjostedt, the workings put in sight about 60,000 tons of ore. The average of a large number of assays showed the ore to contain 2.82 per cent. nickel and 1.70 per cent. copper. The Strathcona deposit was discovered by an Indian named Michel Winde-Kemsaw[3] 15th July, 1889, and patent issued to Thomas Barnetson Ross and Donald Campbell MacTavish 21st October, 1890. Both grantees were in the employ of the Hudson Bay Company, and named the mine after Lord Strathcona, long the governor of that company.

Still proceeding southwesterly along the contact, one comes to the Levack mine, an account of the discovery and taking up of which has already been given. This mine is being actively opened up and worked by the Mond Nickel Company, and constitutes one of that company's most important sources of ore supply.

The Contact Again Concealed

Between the Levack mine and Windy lake, a distance of three miles or more, partly in Levack township and partly in Dowling, the contact is hidden by gravel. Magnetic readings indicate the presence of ore under the drift, and a number of claims have been staked on the strength of these indications by Rinaldo McConnell and others. No actual body of ore has yet been located.

[1] The Nickel Industry, p. 91.
[2] Ibid, p. 91.
[3] Probably the same as the discoverer of the Ross mine, W R 5.

Southwest of Windy lake, in the township of Cascaden, on lot 4 in the third concession, Henry Ranger has staked a claim on a showing of ore. Between the lake and lot 8 in the first concession, where the norite contact crosses the northern boundary of Trill into that township, Henry Ranger and Michael McCormick have taken up claims on some five exposures of gossan and ore. There is said to be a good showing on the creek which crosses the northwest part of lot 7 in the first concession.

As already stated, the contact continues through the township of Trill in a nearly due south direction, until the vicinity of the Sultana mine is reached, where there appears to be some uncertainty regarding its course. An account of the discoveries in Trill is given above.

The greater part of the work of searching the northern norite horizon was carried out in 1897, 1898 and 1899. Among the leading prospectors were the Rangers—Xavier, Fred and the veteran Henry—Isaac Whistle, Ernest McBride, Fred Brisebois, Arthur Belfeuille, John T. Newton, Russell Cryderman and others, mainly from Sudbury. Much of the surface, both on the northerly band or "off-set" and on the main contact, between the norite and the granite or gneiss which abuts upon it, is covered with soil, and so is hidden from view, and there appear to be barren stretches of rock in which the conditions favouring the deposition of ore were absent, but little real exploratory work has been done on any of the locations west of the Whistle mine. Not all of the locations which have been surveyed and taken up on the northern range can be expected to produce ore in paying quantity, but on the other hand, the fact that large and important ore bodies have not been uncovered, is not to be taken as indicating that such bodies do not exist. The lack of transportation facilities; the ability of the mines of the southern range to supply the demand for nickel, practically up to any point which that demand is likely soon to reach; and perhaps also the reputation of the northern ore for carrying less nickel than that of the older areas, have combined to retard the development of the newer sections. Coleman, who examined the basic edge of the norite band from east to west, says:[1]

Taking the northern range as a whole, the number of ore bodies of promise is not great, though at least two portions, northwest of Joe's lake and at the beginning of the Foy offset, are known to contain deposits of importance.

The Alexo Mine

That nickel ore of the Sudbury type is not peculiar to the area or the geological relationships of Sudbury was shown by the discovery of highly nickeliferous pyrrhotite in the township of Dundonald, some 130 miles due north of the nearest point on the northern nickel range, say the Whistle mine. O. L. S. Griffin, who laid out the township in 1904, noted "a very strong variation of the compass" along a ridge of rocks in the southeastern part of the township. Following up the hint, a prospector named Alexander Kelso, on 23rd Feb., 1908, discovered a vein carrying nickel and copper which he staked out as a mining claim, and for which patent issued to himself and others under the name of the Alexo Mining Company, 16th December, 1909. The deposit lies at the contact of a soft serpentine rock,

[1] The Nickel Industry, p. 90.

derived from peridotite, and a hill composed of andesite. It is situated on the northeast quarter of the south half of lot 1 in the fourth concession of the township, and is about three-quarters of a mile from the Porcupine branch of the Timiskaming and Northern Ontario railway, on which a switch has been built for loading the ore. Assays of the ore give as high as 11.46 per cent. of nickel, but a considerable proportion of the ore is of lower grade. Compared with typical Sudbury ore, there is much less copper. The production of ore up to 31st December, 1916, amounted to 34,650 tons, all of which went to the Mond Nickel Company, by whom it was smelted with the ore from the company's own mines. The shipments averaged over 4 per cent. nickel.

In comparison with the large ore bodies of the Sudbury district the Alexo deposit is of small size, but it is significant of the possibility of other deposits being found where the geological conditions permit. The neighbourhood of the Alexo is in the main covered with drift, and so far no extensions or duplications of the vein have been found. An examination of the geology of the area was made during the summer of 1916 by M. B. Baker, of Queen's University, Kingston, on behalf of the Bureau of Mines, which may be expected to throw some light on the prospects for further occurrences. In the township of McCart, which lies north of Dundonald, prospecting in 1915 and 1916 has located other areas of serpentine with pyrrhotite carrying nickel, mostly in too small proportion to be classed as ore. In some stringers, however, the percentage of nickel is high.

The Cobalt Silver Mines

The silver ores of the Cobalt district should also be mentioned here as a source of nickel. Though the first find, made by James McKinley and Ernest Darragh, at the southeast corner of Long (now Cobalt) lake, in the late summer of 1903, was of silver, samples of a bright copper-hued mineral from the same neighbourhood were passed from hand to hand in the early autumn of the same year, under the impression that the ore was one of copper. Examination showed it to be niccolite, and investigation of the source revealed that the chief value lay in the silver, and that as a matter of fact, one of the richest silver fields ever found in any part of the world had been located. Besides niccolite, the ore of Cobalt contains other arsenides of nickel, including smaltite and chloanthite. The avidity with which the silver mines have been worked has brought to the surface many tons of nickel, much of which has been wasted, but methods of treatment have been steadily improved until now a large part of the output is obtained at the silver refineries in the form of nickel oxide or metallic nickel, or is disposed of by the mills at Cobalt as residues which carry cobalt as well. As nothing is paid for the nickel in the ore, no assays are made for it by the mining companies. Definite statistics cannot therefore be given, either of the quantity of nickel which has been raised from the mines of Cobalt, or the quantity which has been recovered. To the end of 1916, it is probable the nickel contents of the Cobalt ores amounted to at least 4,000 tons.

CHAPTER III

The Operating Nickel Companies

Introduction

For nearly fifteen years the whole of the great and highly profitable industry connected with the production of refined nickel from the vast deposits of nickel-copper ores in the Sudbury district has been divided between two powerful corporations. Both companies mine, smelt and refine their own ore, and possess their own process of refining; both produce their refined metal product outside of Canada, and neither is a Canadian company. Other companies, British, American, and Canadian, some of them with excellent promise of success, have operated mines, erected plants, or have been otherwise engaged in the industry. In no case has any of their undertakings been permanent or successful. The history of the nickel companies is, in large part, the history of the industry. Their operations, personnel and experiences of failure or success, have been factors in its development, and with other aspects of their internal affairs, are accordingly matters of public interest. The material facts down to March, 1912, can be gathered from the previous publications on the district, and in what follows free use has been made of the information contained in them, and especially in the standard reports of Dr. A. E. Barlow[1] and Dr. A. P. Coleman[2].

The Report of the Royal Commission on the Mineral Resources of Ontario (1890) makes many interesting references to the growing importance of the Sudbury district. The then recent experiments and discoveries of Hall and Riley in connection with alloys of nickel and steel, first published in 1889, which have so powerfully influenced the demand for nickel in later years, are described at some length, and the statement is made that "if the claims made for the alloys are fully borne out by practical application in the metallic arts, the importance of the inventions to this Province can hardly be over estimated." With acute prevision the report states, "the most promising mineral works in the Province at present are the mining and smelting of copper and nickel ores in the vicinity of Sudbury."

It is interesting to observe that this prediction has been confirmed. Notwithstanding the growth of the mining industry, and the great production of precious metals from Cobalt, Porcupine and other new sections of Ontario in the intervening years, the nickel-copper ores of Sudbury have maintained their pre-eminence and still constitute the most important mining industry of the Province.

The report was made at a time of great activity in the Sudbury district. Although mining in earnest had commenced only in 1886, there were three substantial companies then in operation: the Canadian Copper Company at Copper Cliff, the Dominion Mineral Company at the Blezard and Worthington mines, and the long established metallurgical firm of H. H. Vivian and Co. of Swansea, at the

[1] Nickel and Copper Deposits of the Sudbury Mining District, Geol. Sur. Can., 1904, reprinted 1907.

[2] The Nickel Industry, Dept. of Mines, Ottawa, 1913 Also The Sudbury Nickel Field, Ont. Bur. Mines, Vol. XIV, Part III, 1905.

Murray. Two furnaces were in operation at Copper Cliff, and the two other companies were erecting similar furnaces at their respective properties. The peculiar qualities and value of nickel steel were attracting the interest of the armour-plate houses of Europe and America. In the previous year, Sir Charles Tupper, the High Commissioner for Canada at London, in company with a representative of the United States Navy, and of the Canadian Copper Company, had visited the leading steelmakers and ordnance manufacturers in Germany, France, and the United Kingdom in the interests of the Sudbury deposits and his report of November, 1889, to the Prime Minister gives a highly encouraging account of the result. A few months later, as a result of tests made at the Annapolis Navy yard, nickel steel was definitely adopted by the United States Government for armour-plate, and a million dollars was appropriated by Congress to purchase Sudbury nickel matte for that purpose. The Sudbury deposits had been well advertised to the world.

Early Conditions of Nickel Industry

It is doubtful whether the report of a Commission a few years later would have been so hopeful in its tone. Of the three pioneer companies, only the Canadian Copper Company had survived. Of the two that failed, one was identified with an English house of world-wide reputation, and its withdrawal from the field in 1894, after sustaining a loss, said to be $375,000, was a severe blow to the Canadian industry. The Dominion Mineral Company, which had the support of a strong group of Canadian business men, stopped mining in 1893, and its smelter was closed down as soon as the accumulated ore had been treated. The new industry was beset by grave difficulties. The first great difficulty was to secure an economical treatment of these troublesome ores. The second was the limited demand for nickel, aggravated by a trade prejudice in favour of New Caledonia nickel, which controlled the market. The total consumption of the world in 1888 did not exceed 1,000 tons a year. The new Sudbury field was capable of producing many times the total quantity of nickel required by all consumers, and the vital question immediately arose of finding or creating a market for the nickel its deposits would produce.

As late as 1900, two years before the International Nickel Company was formed, approximately 65 per cent. of the world's market was supplied by nickel made from New Caledonia ores, and 35 per cent. from Canadian ores. New Caledonia nickel, moreover, had not only an established market, but it had an established reputation. British specifications for the Imperial government all specified New Caledonia nickel. The Mond Nickel Company found serious objections among the British armour-plate manufacturers to the use of Canadian nickel for the requirements of the Imperial navy and army, and it was only after elaborate and expensive experiments and tests had been made at the company's expense, including trials by the Admiralty, that they were finally removed, and Canadian nickel accepted for these important uses. New Caledonia nickel has enjoyed for many years, moreover, a tied market of the principal consumers in Great Britain and other countries, through the close business connections of the leading French producer, Le Société Anonyme le Nickel—generally referred to as Le Nickel—with the great European armament houses. This strong company, which has

the financial backing of the Rothschilds, is the chief rival of the Canadian companies. It has had for many years, and still operates, two nickel works in Great Britain, near Glasgow and near Birmingham, one in France at Havre, and one in Germany at Iserlohn in Westphalia. Sir Charles Tupper refers in his report to this Company and to these four refineries, and says: "This company has up to the present time produced nearly all the nickel consumed in the market of the world, and of course has regulated the market for this article." His party called at the company's office in Paris, and found the management quite unwilling to believe that there were any nickel deposits in the world outside of their own, of any importance.

The Anglo-French Nickel Company, Limited, an English company with refining works near Swansea in Wales, which produces roughly 4,500 tons of refined nickel a year, obtains its raw material wholly from Le Nickel. All the shares are held by leading British armour-plate and steel companies, and by Le Nickel in practically equal holdings among them.

Another company, the Steel Manufacturers Nickel Syndicate, Limited, incorporated in 1901, with a small capital, is in very close corporate and business relations with Le Nickel and the Anglo-French Nickel Company. The shareholders of the latter company and two other British houses (including Vickers, Limited, and Armstrong, Whitworth & Co.), Fried. Krupp of Essen, Germany; Schneider & Co., of Le Creusot in France, an establishment which is to France what Krupp is to Germany; two other French armament companies; an Austrian company, and an Italian company, all holding 125 shares each, are the shareholders. The Commissioners understand that the Nickel Syndicate had acquired an option on nickel properties in New Caledonia, with the intention of procuring their own supplies of ore. Soon afterwards the Syndicate entered into a long term contract with Le Nickel for the total requirements of the Syndicate members. At the same time arrangements were made by the Anglo-French Nickel Company (the refining company) with Le Nickel (the Caledonian producer), by which the latter agreed to supply the Anglo-French Company with all the raw material required for its refining works in Wales, of which the product is doubtless taken by the shareholders of one or other of the associated companies.

This is not an association of nickel producers, but a combination of the leading armament makers of Great Britain and Europe, who control between them the principal sources of demand to secure their supplies of nickel on special terms from New Caledonia ores, owned by the French company Le Nickel, with holdings in both the English companies. The British shareholders in these companies are represented on the board of Le Nickel. The community of interests has undoubtedly influenced prices and strengthened the demand for New Caledonia nickel. The Mond Nickel Company, presumably by accepting its conditions, is said to have secured an opening for its Canadian nickel for a fair share of this trade.

New Caledonian Rivalry Overcome

Notwithstanding the advantages that have been indicated, the statistics show that New Caledonia has not been able to keep pace with Ontario. In 1900, as already stated, New Caledonia produced 65 per cent. and Ontario only 35 per cent.

of the world's nickel. The world's output has increased sixfold since that time, and Ontario now produces about eighty per cent. of the whole. The production of Ontario in the last fifteen years has increased ninefold in quantity, the production of New Caledonia by one-sixth only. The output for Ontario for 1916, stimulated by war demands, was eight times as much as that for New Caledonia in 1915, the last year for which statistics are available. The chief factor that has enabled Sudbury to out-distance its only serious rival is the great difference in the size of the ore bodies in the two countries. The Ontario deposits are measured in millions of tons, the deposits of New Caledonia in hundreds of thousands at the highest.

The able manner in which the operations of the two Sudbury companies have been conducted in cheapening production, and the success of their efforts to widen the markets and extend the uses for nickel, have made the most of the conditions in their favour.

The history of the Sudbury companies supports the conclusions of previous writers that the control by a producing company of a process which can refine the ores at reasonable cost is of vital importance. Dr. Coleman says,[1] "Most of the companies which have failed did so because of lack of capital, or of experience, or because they had no well worked out method of refining the matte. The smelting of roasted ore to make standard matte and the treatment of this matte in bessemer converters, so as to raise its contents of nickel and copper to 70 or 80 per cent., is comparatively simple. The real difficulty comes in the refining of the bessemer matte, and up to the present (1904) only two processes[2] seem to be successful on the large scale, and both are in the hands of companies which have their own supplies of ore." Dr. Barlow is of the same opinion, as follows:[3] "Very early in the history of the region it was patent to everyone that to share in the full benefits of the industry the same individuals or company must control the whole of the operations necessary to manufacture the finished product."

The early history of the nickel industry is a record of continuous struggle against the difficulties which centred about these two questions of economical refining and a limited market. Unfailing ore supplies, the remarkable expansion of the nickel steel trade, new markets, new uses for nickel, and the business ability and technical skill of the executive and operative staffs, have been the chief factors in the great success in later years of the two companies that have been able to overcome them.

The Canadian Copper Company

The history of the Canadian Copper Company possesses peculiar interest, for as Dr. Barlow has said:[4] "The history of the development of mining in the Sudbury district is in the main that of the Canadian Copper Company."

The company was promoted by the late S. J. Ritchie, of Akron, Ohio, to whom the inauguration of the great nickel industry of Ontario is more directly due than to any other man. Mr. Ritchie had been interested for some time with capitalists from Ohio in extensive holdings of iron ore lands in Hastings county. Consider-

[1] Ont. Bur. Min., XIV, 1904, Part III, pp. 144-5.

[2] Since 1904, a third process, the electrolytic, has been introduced and used with success. Dr. Coleman alludes to this process in his later Report on the Nickel Industry, p. 164.

[3] Nickel and Copper Deposits of the Sudbury Mining District (Reprint 1907), p. 45.

[4] Ibid, p. 25.

able work had been done and money expended in developing the properties, and a controlling interest in the Central Ontario railway had been acquired to provide the necessary railway facilities. By reason of the composition of the iron ore, the undertaking had not been a success.

Mr. Ritchie had faith in the mineral wealth of the Province; he had strong financial support; and he had a railway on his hands that had power to own and operate mines. In the course of a systematic search for mining properties that would provide business for the railway and protect its securities, he investigated the reported discovery of large copper deposits north of Georgian Bay, with the result that the Canadian Copper Company was organized by him to take over and operate a number of promising prospects he had secured in the Sudbury region in the summer of 1885. These properties included what have since become the Copper Cliff, Stobie, and McArthur or No. 2, mines, as well as the great Creighton, and from his purchases the bulk of the ore supplies of the company to the present time have been derived. The Evans mine, the Frood and other properties were bought shortly afterwards.

The company was incorporated on 6th January, 1886, with a capital of $2,000,000, afterwards increased to $2,500,000, under the general laws of the State of Ohio, and throughout all its extended operations in Ontario it has remained a foreign corporation. The head office of the company is still Cleveland, Ohio, and its annual meetings are held in that city. Mr. Ritchie and his Ohio associates in the Central Ontario enterprise were the incorporators and first shareholders of the company. In addition to himself, these were Senator Henry B. Payne, Judge Stevenson Burke, H. P. McIntosh, for many years secretary of the company, Myron W. Keith and George G. Allen. Mr. Ritchie was the first president of the company, and Judge Burke the first vice-president. Thomas W. Cornell became president in September, 1886, and occupied the position until January, 1891, when he was succeeded by Judge Burke, who remained president of the company until the formation of the International Nickel Company in 1902. Mr. Cornell became vice-president in January, 1891, and was succeeded in 1893 by Charles W. Bingham, who was the vice-president until June, 1902.

Nickel as Well as Copper

As the name of the company implies, the Sudbury properties were at first regarded as copper deposits only. The discovery that the ore contained nickel as well, which was made in 1887, completely changed the situation. The combination of circumstances that led Mr. Ritchie to recall his experiences with nickel ten years before, and to enable him to secure the interest and co-operation of the Secretary of the United States Navy, are detailed in an extremely interesting communication from him, which has been preserved in the appendix to Dr. Coleman's first report.[1] Mr. Ritchie says:—

> We found we had a great nickel deposit instead of a great copper deposit, or, to be more correct, we had a great nickel and copper deposit. As the world's annual consumption of nickel was then only about 1,000 tons, the question was what was to be done with all the nickel which these deposits could produce. I at once recalled the experience I had with John Gamgee at the Navy yard at Washington, ten years previous to this time, and it occurred to me that nickel could be used with success in the manufacture of guns and for many other purposes as an alloy with iron and steel.

[1] Ont. Bur. Min., Vol. XIV, 1904, Part II, p. 170 *et seq.*

Mr. Gamgee, to whom he refers, was an English inventor who had interested a committee of the United States Senate in a remedy he had devised for yellow fever, which involved the building of a refrigerator ship on which a frost temperature to destroy the germs could be maintained. It was necessary to find an alloy that could withstand the pressure from the ammonia gas he intended to use for that purpose, and the association of nickel and iron by nature in meteorites suggested the possibility of a similar alloy for his requirements. With the assistance of Mr. Ritchie, a small quantity of nickel was procured, and a number of experiments and tests with the additions of varying percentages of nickel and iron were made, with surprising results. Mr. Gamgee's conception for other reasons was never realized but the experiments played an important part in subsequently providing a demand for nickel for the United States navy, which materially assisted in the early development of the Sudbury properties. Mr. Ritchie's conclusion that, "from the sulphur in iron ores in Hastings county in Ontario, aided by the composition of the meteorite, has grown all the nickel and nickel steel industry of this hemisphere, as well as very much of the industries in the old world," requires a good deal of qualification. The fact remains, nevertheless, that he is entitled to be regarded as the founder of the new industry in this Province.

Terms of Company's Charter

To obtain the necessary authority to exercise its corporate powers in Canada, the company obtained a short special Act from the Dominion Parliament in 1886 (49 Vic. cap. 99). The first clause vests the company with its corporate powers in Canada. Clause 2 is as follows:—

> The company shall have full power to sell the produce of their mines in any part of Canada or elsewhere, and to establish treating or smelting works in any Province of Canada as in the interests of the company may be found expedient.

The recital states that the incorporators desired power to "sell and treat its ores in such part or parts of Canada or elsewhere as they deemed proper." The inference that the distinction between the powers requested and the powers granted was deliberate, is confirmed by the proceedings in the Private Bills Committee.

The late Hon. W. B. Ives, in a letter written to Mr. Ritchie under date of April 29th, 1897, states in reference to this Act and a similar Act respecting the Anglo-American Iron Company:—

> I was Chairman of the Private Bills Committee of the House of Commons at that time, and have to-day refreshed my memory by looking over the original records. I find that the bill as brought before the Committee asked power to establish treating or smelting works in any Province of Canada or elsewhere. The words ''or elsewhere'' were stricken out by the Committee with a view to forcing the companies to treat and refine their ores in Canada.

Mr. Ritchie himself says on the subject:—

> I procured the passage of both these Acts. . . . The matter of refining and producing fine metals by these companies was raised in Committee while the bills were under consideration, and I was obliged to agree on the part of the company that the company should do its refining in Canada as a condition of the passage of these Acts by the Committee. John Bell stood by my side, and as attorney for the companies, made a like pledge to the Committee.

Mr. Bell was the well known solicitor for the Grand Trunk Railway, and was solicitor as well for the Central Ontario Railway and for this company.

There is no doubt that the company obtained its corporate status in Canada upon the faith of this undertaking, and, as will be shown, the company intended to refine in Canada, and made repeated efforts to obtain a process of its own with that end in view, until the amalgamation with the refining works in New Jersey in the formation of the International Nickel Company gave a new complexion to the situation.

Beginnings and Growth of Industry

The Lady Macdonald mine was the first property on which any work was done. This was during the summer of 1885, before the company was formed. In May, 1886, work was commenced at the Copper Cliff, and Dr. Barlow says that the first shipments of ore made from the district were obtained from the surface openings of this mine. The Stobie and Evans mines were opened up in that year, and these three properties supplied all the ore that was produced until 1898.

The total production of ore for 1887 was 4,800 tons, which was increased in 1888 to 11,840 tons and in 1889 to 45,988 tons. The Evans mine appeared this year for the first time as a producer, supplying 11,368 tons. In 1890 the total output had advanced to 71,778 tons. In the next three years there was a marked decline. These were the days of trial for the industry. The Vivians withdrew from the field in 1894, and the Dominion Mineral Company stopped mining in 1893 and closed down its smelter. The Canadian Copper Company had 2,500 tons of standard matte on hand for which no sale could be obtained. A very fortunate order from the United States Government relieved the situation, and in the following year the company was able to pay its first dividend. The Spanish-American war may have had some influence in the enlarged output of 1898, when the highest production of the company so far, amounting to 137,578 tons of ore was reached, which was increased in 1899 to 177,568 tons. In 1901 the total production was 268,706 tons, or over 35 per cent. higher than in any previous year. The growth of the industry since that date may be shown by the following figures. The total production for the period 1887 to 1902 inclusive was 1,581,505 tons of ore, containing 46,336 tons of nickel and 40,309 tons of copper. The production for 1903 to 1915 inclusive was 6,034,952 tons, the metal contents being 237,354 tons of nickel and 106,614 of copper. The Creighton mine alone, since it began producing in July, 1901, has accounted for 4,753,433 tons of ore to March 31st, 1916. This is unquestionably the greatest nickel mine in the world, and its ratio of 4.43 per cent. of nickel to 1.56 per cent. of copper explains the great increase in the nickel contents as compared with copper since it became the principal source of the company's ore supply. During the calendar year 1916, 1,227,187 tons of ore were raised and 1,167,070 tons smelted by this company.

The First Smelting Works

The report of the Royal Commission on the Mineral Resources of Ontario (1890) describes the smelting works and practice at that time. The first furnace was blown in on December 24th, 1888, but, owing to a fault in the construction, regular work was not commenced until February, 1889, and in the four months ending with May, the total product of matte was about 1,200 tons, which would give at the refinery 320 tons of copper and 170 tons of nickel. A second furnace of

the same capacity of about 150 tons a day, was set up during the summer of 1889 and was blown in on the 4th of September. The secretary of the company gave the following particulars of operations:—

No. 1 furnace had used 31,268 tons of ore and produced therefrom 3,849 tons of matte, averaging about 18 per cent. copper and 13 per cent. nickel. Furnace No. 2, running 73 days to December 31st, had used 9,740 tons of ore and produced 1,210 tons of matte, averaging about the same per cent. of copper and nickel contents.

In 1889 the East smelter, as it was called, was capable of treating 700 tons of ore a day and had cost $250,000. It ceased operating in 1902, and was subsequently burned. In 1891 and 1892 a bessemer plant was provided which was able to bring the matte up 75 per cent. In 1899 an additional smelter, called the West smelter, which commenced operation in December of that year, was erected near No. 2 mine. The West smelter was also destroyed by fire, on 14th June, 1904. In 1900 the Orford Copper Company put up a plant called the Ontario Smelting Works near the present C. P. R. station at Copper Cliff, for the production of high-grade matte by a new method. These works were bought by the Canadian Copper Company in 1902, and were operated until destroyed by fire on 19th February, 1904. The plant was restored, and was used for refining Cobalt ores until 1912. It has been idle ever since, and is practically dismantled. Construction of the present smelting plant began in April, 1903, and the first tap was made on the 17th of July, 1904. The new bessemer plant was started on the 21st of October, 1904, and blown in on the 14th of May, 1908. The existing plant, which is one of the most modern type and equipment, is described elsewhere. For a short time, and while the Ontario Smelting Works and the West smelter were both in ashes, the Victoria Mine smelter was leased from the Mond Nickel Company. The low grade matte was bessemerized there until the converter plants at Copper Cliff were finished. In the winter of 1915-16 a new roast yard was constructed near the Vermilion river, which is reached by a spur from the Algoma Eastern Railway at mile 16. The yard is 7,500 feet long and contains four parallel railroad tracks. There is room for at least 350,000 tons of ore. The cost of plant to March 31st, 1916, is given as follows: Mining plant, $1,684,420; smelter, $3,818,952; railways, $635,870. This is exclusive of the plant equipment and railway lines owned by the power company, the Huronian Company. The cost of its hydro-electric plant, including dams, etc., was $681,089.

Experimenting with Refining Processes

The practical question of refining its matte has always been a critical one with this company. The Commission of 1890 was informed that shipments had been made to Philadelphia, New York, Swansea, Liverpool and Hamburg for treatment. Sir Charles Tupper's report mentions the treatment of the Sudbury ores at different works in Great Britain, among them the well known firms of Tennant & Sons, the Vivian Works at Swansea and Henry Wiggin & Co. at Birmingham. James Riley, who made the famous report on nickel steel alloys, was the manager of the first named firm. The Hamburg house, which was connected with the largest factory of German silverware in Europe, located at Berndorf, was much interested in the Sudbury product, and was willing to make a ten years' contract for a substantial supply. Le Nickel, the New Caledonia company, then had the two nickel plants in

Great Britain which it still owns, and a few consignments went to its works at Iserlohn in Germany. The American refineries that were tried would doubtless be the works of Joseph Wharton & Co., near Philadelphia, and Col. Thompson's Orford plant in New Jersey. The charges in Europe were exorbitant, and on a shipment to the Vivian works the company, according to Dr. Peters, did not realize a dollar a ton. There were works which could refine nickel, but a process specially adapted to the Sudbury ores was not easy to find. The saltcake process with repeated smelting of "tops" and "bottoms," which was finally adopted, is said to have been brought over from Wales, but was undoubtedly much modified and improved at the Orford plant.

Dr. Edward Peters, the manager of the company until 1890, and an experienced metallurgist, had been associated with Col. Thompson at Constable Hook and elsewhere, and he was fully alive to the importance of the refining end of the industry. In 1889 he had recommended the erection of a refinery at Cape Breton, and it may be noted that the suggestion of the Canadian seaboard was renewed by the International Nickel Company in its correspondence with the Dominion government in 1916. In 1891, M. Garnier, a French expert on New Caledonia ores, was retained by the company to work out a process for the Sudbury ores. He put up a small plant at Cleveland, where he was able to produce an 80 per cent. matte, but he got no farther. In a letter written in 1891, the president, Judge Burke, says:—

> It is the purpose of the company to smelt all its ores in Canada and to refine all its nickel and copper there, except such as may be required for use in the United States. The company is now erecting bessemer refineries at Sudbury at a cost of about $50,000, by means of which it expects to bring its matte up to a fineness of about 95 per cent. It is the purpose also to erect, at Sudbury, works for making pure alloys of nickel and copper, and also pure copper and pure nickel as soon as the best works can be considered. The company has erected no works in the United States, and has not even selected a location or site for its works there. We regard our mines and works as essentially Canadian, and intend to conduct them as such as far as it can be done consistently.

The company experimented without satisfactory results with the Hoepfner process, afterwards transferred to the Hoepfner Refining Company at Hamilton, which contemplated the refining of Sudbury ores in that city. The metallurgist of the company was sent to England to study the Mond process, which was eventually rejected after a year's investigation, on the ground that it was probably unsuited to the climatic conditions of the Canadian winter. A small electrolytic refinery was established at Cleveland, and refined nickel was produced from it. It is alleged, however, that its cost in comparison with the Orford process precluded its adoption. In the meantime, Col. Thompson's Orford company at New Jersey was doing the bulk of the refining, and after its process had been perfected, it was giving better results to the company than were promised by any of its independent efforts to secure a method of its own.

Reasons for Refining in Canada

It should be assumed that the company was endeavouring to comply with its undertaking to the Parliament of Canada that it would refine its nickel in this country. There were cogent commercial reasons, apart from this obligation, in favour of that policy. It would be better business for the company to sell nickel instead of matte; to do its own refining, and be independent of the Orford works.

Mr. Alexander Gray, whose monograph[1] gives intrinsic evidence of reliable private information, thus describes the attitude of the company:—

Realizing that political and economic considerations invited the provision of a Canadian refinery, the Canadian Copper Company sought a process of its own, rather than be tied up to one refinery in New Jersey. In this endeavour there was the additional incentive, that it would be injudicious to patronize the Orford Works and leave it within the power of Col. Thompson to operate nickel mines on his own account. To meet this latter contingency, and to satisfy Canadian sentiment, if possible, the Canadian Copper Company decided it must have its own process of refining, and further that this process of refining must be done in Canada.

In objecting to the imposition of a duty on nickel matte before the Committee of Ways and Means at Washington in 1896, President Burke is reported to have said:—

And of course the putting of a duty upon either nickel ore or nickel matte would result necessarily in the refining of this product in Canada, or in Great Britain, or in Germany.

To which he adds:—

We have preferred to have this work done in this country (the United States). We have preferred to give our people the benefit of it.

While allowance may be made for the occasion and purpose of these remarks, it is not easy from the available material to determine the real intentions of the company on the subject. In any case, the objections that have been so strongly urged in recent years on commercial and metallurgical grounds against refining in Ontario, were not pressed until a later date, and after the combination of the mining and refining companies in the International Nickel Company.

Down to the end of 1901, the company had spent on these various experiments on refining $300,000, and large sums had also been laid out in the erection and improvement of plans and buildings. The surplus earnings of the company were largely absorbed by capital investments, and no dividends were paid until 1894, when a dividend of 8 per cent. was declared. In 1895 and 1896 the dividends were 7 per cent. and 8 per cent. respectively, and from 1897 to 1901 the annual dividends were 12 per cent.

The costs of refining were high in proportion to other operating costs and, as the Orford process had no real competitor, probably excessive. The earlier agreements with that company are not available, but in after years the prices paid by the Orford company in purchasing the matte were fixed by agreement at 6¼ cents a lb. for copper and 8½ cents for nickel contents, subsequently increased to 7 cents for copper and 10 cents for nickel per pound, f.o.b. Copper Cliff, which was all the company received from the product of its mines.

The nickel question had recently been engaging public attention in Ontario, and by the Act of 1900 (63 Vic. cap. 13) a royalty which the producers regarded as prohibitive, had been imposed upon nickel not refined within the Province. The competence of the legislature to pass such legislation was called in question. A petition for disallowance on that and other grounds was presented to the Dominion Government, and after communications between the Dominion and the Province, it was finally agreed to refer the validity of the impeached statute to the Supreme Court. The question was never so referred; the royalties were never imposed under

[1] Organization and Equipment of The Canadian Copper Company, by Alexander Gray (1911).

the statute, which was repealed in 1906. It is not unlikely that the company interpreted the net result as removing any danger of the enforcement of refining in Ontario. The Mond Company claim that about this time they received the approval of the Ontario Government to their proposal to erect their plant and do all their refining in Wales.

Amalgamation of Producing and Refining Interests

The crucial requirement of the company was the possession of its own refinery. There was no ground for concern on the subject of ore. The Orford Copper Company had a refining plant that had demonstrated it could refine Ontario nickel cheaply. It has been suggested that the Orford Company, on its part, was anxious to acquire nickel ore to be independent of the mining company, and that it was looking for that purpose towards New Caledonia. It was the day of mergers and combinations. All conditions were favourable to a consolidation in one strong corporation of all the competing interests concerned in the production and sale of nickel. The amalgamation of the producing and refining companies had mutual attractions, which were enhanced, having regard to the recent Ontario legislation of 1900, by the opportunity to acquire substantial acreage in the rival field of New Caledonia. With the assistance of friendly interests in the steel trade, the outcome of negotiations for amalgamation was the formation of a holding company, "International Nickel Company," which was incorporated under the laws of New Jersey in April, 1902. The future history of the company is merged in that of the new holding company.

International Nickel Company

The authorized capital of the new company was $24,000,000, divided into $12,000,000 of preference shares and $12,000,000 of common shares, with an authorized issue of $12,000,000 in bonds. The company acquired the whole of the capital stock of the Orford Copper Company and the American Nickel Works, and of the New Caledonia company, Société Minière Caledonienne; 24,900 shares of the Canadian Copper Company; 33,559 shares of the Anglo-American Iron Company; 2,373½ shares of the Vermilion Mining Company of Ontario, Limited; and 140,906 shares of another New Caledonia company, Nickel Corporation, Limited, giving a strong majority control of these corporations all possessing nickel deposits. The consideration was the issue of first mortgage 5 per cent. bonds to the extent of $9,890,836.51, and 6 per cent. preferred stock and common stock of the par value of $8,912,626.09 each, making a total bond and stock liability of $27,716,088.69. All the remaining shares of the Ontario mining companies, the Canadian Copper Company, the Anglo-American Iron Company, and the Vermilion Mining Company, and 912 shares of Nickel Corporation, Limited, were eventually purchased for, roughly, $160,000 cash. In October, 1902, an additional issue of $500,000 of bonds was sold at par and the proceeds used for working capital. The Huronian Company, Limited, incorporated in Ontario in March, 1902, was purchased for cash at a later date.

From this time forward, the Canadian Copper Company is a subsidiary of the new company. All the properties in Ontario, other than the water power plant and

accessories, continue to be held in its name, and it conducts all mining and smelting operations up to the production of high-grade bessemer matte. The refining is done exclusively at the Orford works at Constable Hook in New Jersey.

It is deplorable that the new arrangement did not provide for refining in Canada. The acquisition of refining works in the United States and of properties in New Caledonia, was tantamount to a declaration to the Ontario government that the new corporation did not intend to abide by the undertaking and reiterated promises of its predecessor, the Canadian Copper Company, that the product from Ontario ores would be refined in Canada, and it is unfortunate that the challenge was not accepted. The enterprise and achievements of the company have not been received with the pride and satisfaction the people of the Province would have taken in a successful Canadian industry that had kept its faith and produced refined nickel within the Province.

A short account of the constituent companies may be of interest, as follows:—

The Anglo-American Iron Company

The Anglo-American Iron Company has already been mentioned. It was incorporated in the State of Ohio on the same day as the Canadian Copper Company (6th January, 1886), with the same incorporators, and was authorized by special Act of the Parliament of Canada (49 Vic. cap. 98) to exercise its powers in Canada. The petition for incorporation was treated by Parliament in the same way as the similar petition of the Canadian Copper Company, and the same undertaking was given on its behalf that its treatment work should be done in Canada.

The company was formed to take over the iron properties of the promoters in central Ontario, all of which were duly conveyed to it by the original owners, Messrs. Ritchie, Payne and Maclaren, and William Coe, of Madoc, in consideration of the issue to them of paid up shares in the company. Its chief interest in the nickel industry lies in the fact that the inception of the Canadian Copper Company was due to the failure of the undertaking with which its promoters had been associated. The authorized capital was $5,000,000, of which $3,400,000 was issued fully paid. Substantial control of the company had been acquired by the Canadian Copper Company, and for some time prior to 1902 its directors and executive were provided by that company, which was able to carry $3,355,900 of the capital stock into the consolidation. All the outstanding shares were finally purchased by the International Nickel Company. The Crean Hill mine was bought by this company and was operated in its name. The annual returns of the company show that it continued to do a little lumbering and development work in connection with its large holdings of lands in Hastings county. In the reorganization of 1912, hereafter mentioned, the assets and liabilities of the company were transferred, its capital stock cancelled and its corporate existence duly terminated.

The Orford Copper Company

The Orford Copper Company was incorporated under the laws of New Jersey, July 25th, 1887, with an authorized and issued capital of $350,000, the whole of which was acquired by the International Nickel Company. This company gets its name from the township of Orford in the Province of Quebec, its president, Colonel

Thompson, having been interested many years before in a mine there, which contained a small amount of nickel. A company called the Orford Copper and Smelting Company was incorporated by special Act of the Province of Quebec in 1878, investing the company with powers to mine, manufacture and sell nickel, phosphate, copper and other minerals. The authorized capital was $300,000, and the original incorporators were Charles C. Colby, Robert G. Leckie, Walter W. Beckett, William E. C. Eustis and Robert M. Thompson. Small beginnings were made in the way of treating the ore in Quebec, which were not successful, and the owners turned their attention to a low grade copper ore from property near at hand. The United States tariff laws, which placed a duty on copper and gave free entry to matte, were the principal reasons for the erection of a refinery for the copper at Constable Hook in New Jersey, which received the name of the company, and was the nucleus of the present refining plant of the International Nickel Company. The name of the company was changed by different special Acts for special purposes, and finally in 1888, to the Eustis Mining Company, of which Mr. Eustis appears as president. Mr. Eustis had been associated with Col. Thompson in the New Jersey refinery and similar enterprises, and this probably represents the stage in the negotiations between them by which he took over the Quebec company and its assets, and transferred his rights in the refinery to Col. Thompson, who appears to have formed the Orford Copper Company in New Jersey during the preceding year, to carry on that business.

In the reorganization of 1912 all the assets and liabilities of this company were transferred to the reorganized International Nickel Company; its capital stock was cancelled, and its corporate existence ended.

The capital investment of the company in buildings and equipment was valued at $2,426,206, and it owned in addition 23 acres of land including riparian rights valued at $500,000. It had also acquired for purposes of extension, 111.4 acres of land with large water frontage, situated at Carteret, N.J., at a cost of $500,000. Its refinery works are now operated under the name of the "Orford Works" by the International Nickel Company, in whom all its assets have been vested.

The American Nickel Works

The American Nickel Works represents the business which had been carried on for many years at Camden, near Philadelphia, by the late Joseph Wharton, who was a director of the International Nickel Company until his death. Mr. Wharton had been connected for many years with the refining of nickel, chiefly from the ores of Lancaster Gap, Pennsylvania. It was from his works that Mr. Ritchie and Mr. Gamgee got their nickel for their yellow fever experiments in 1876, to which reference has been made, and some of the early shipments from the Canadian Copper Company were consigned to it.

Through dealings with the Drury Nickel Company and the foreclosure of a mortgage, Mr. Wharton acquired the interest in the Chicago mine which that company owned, and it was through the consolidation of 1902 that the Canadian Copper Company obtained the one-third interest it now possesses in that property.

The Camden business was incorporated in Pennsylvania under the name of the American Nickel Works in April, 1902, no doubt with a view to the proposed

combination of nickel interests, with a capital of $100,000, all of which was acquired by the International in 1902. On October 31st, 1905, the company was merged with the Orford Copper Company, which took over all its assets and liabilities. Its corporate existence was terminated in the course of these proceedings.

The Vermilion Mining Company

The Vermilion Mining Company of Ontario, Limited, was incorporated by letters patent under the Ontario Companies Act on the 21st of February, 1888, with an authorized capital of $240,000, on which $151,200 had been paid. The incorporators were Robert J. Tough, and James Stobie, of Sudbury, Alex. G. Duncan of Marksville, Ont., and V. W. Foster and Robert Hill of Chicago. Shortly after incorporation the company obtained a large tract of land in the townships of Denison and Graham, which included the property known as the Vermilion mine, on the issue of partly paid up shares.

The Vermilion mine was first treated as a gold mine. A small mill was put up and some work done on the property at various times, but from lack of capital and other internal causes the practical operations of the company were very limited. Nearly all of the shares were acquired by interests connected with the Canadian Copper Company, and from 1896 the affairs of the company were under the latter's control, and its executive offices occupied by officials of either the Canadian Copper Company or the International Company. There were internal dissensions which resulted in litigation, and an action was brought in 1901, without success, by the few minority shareholders to restrain the contemplated sale of its assets. The few outstanding shares were eventually purchased for cash. In reorganizing the International all the assets and liabilities of this company were taken over by the Canadian Copper Company on the 31st of December, 1911, and its corporate existence duly terminated by surrender.

The two New Caledonia companies which were brought into consolidation, presumably by the Orford Copper Company, which had been looking for connections in that field, had large holdings of nickel lands in New Caledonia of uncertain value. Nickel Corporation, Limited, was one of the Whitaker Wright promotions. The authorized and issued capital of this company, which was incorporated in Great Britain, was £750,000, of which the International owns 141,818 original £5 shares. In 1910 the capital stock was decreased by roughly £75,000, the shares being reduced from £5 to 10 shillings par value, and a few forfeited shares of the original subscription cancelled. Societe Minière Caledonienne was incorporated locally in November, 1900, with an authorized and issued capital of 440,000 francs, all of which is now held by the International Nickel Company. No perpetual charters are issued by the New Caledonia government, and the charter of this company will expire 10th November, 1920.

The two New Caledonia corporations own 9,217 hectares[1] of mineral lands, and are joint owners of 3,848 additional hectares of mineral lands, in the Island of New Caledonia.

The International Nickel Company did some work on the properties of these companies for a few years. In recent years, however, active mining has been dis-

[1] 1 hectare = 2.47 acres.

continued by the company, although a part of the ground is worked under lease by a subsidiary of Le Nickel.

Huronian Company, Limited

The Huronian Company, Limited, is another subsidiary company wholly owned by the International Nickel Company. This is also an Ontario company which was incorporated by special Act in 1902 (2 Edw. VII., Ont., cap. 101) as a power company with ancillary objects. Col. R. M. Thompson, Major R. G. Leckie and Hon. Wallace Nesbitt being three of the incorporators and of the first five directors.

The authorized capital is $1,000,000, of which $500,000 has been issued and acquired by the International Nickel Company on a cash purchase. The water power rights and plant including the hydro-electric plant at High Falls, from which the Canadian Copper Company obtains the electric power for working its mines and smelters, together with 3,865 acres of land, are held and operated in the name of this company, which also holds all the shares of the Upper Spanish Improvement Company, Limited, another Ontario company which had rights on the Spanish river. The cost of the High Falls plant, including the dams, etc., is given as $681,089. The company also owns the right of way and railroad from Turbine to High Falls, as well as the spur to the Crean Hill mine, amounting together to 6.7 miles. This company was at one time employed by the International Nickel Company as a selling company to handle its European sales, and the recent contracts for the supply of nickel to the British Government were made in its name. This arrangement was explained to be a matter of convenience to keep certain branches of the foreign business of the company separate from its American sales, and it has been terminated.

As already stated, the International Nickel Company now owns all the shares of the Canadian Copper Company.

Career of the Consolidated Company

The shareholders of the consolidated company received little encouragement for the first years of its activities. The company passed its dividends even on the preferred shares, which were not cumulative, until the fiscal year ending March 31st, 1906, during which 3 per cent. was paid, and no dividends were paid on the common stock until the eighth year of operation in 1910, when a dividend of 5½ per cent. was paid. In June, 1910, however, the common stock was increased by the issue of $2,670,000, which was issued at par to both preferred and common stockholders to the extent of 15 per cent. of their holdings, following a 25 per cent. cash dividend on the common stock. A further dividend of 7 per cent. in 1911 made a total of 32 per cent. on the common shares for that fiscal year.

The following is a statement of all dividends to the end of the last fiscal year. All preferred dividends of 6 per cent. have been paid to date since the first payment of 1½ per cent. in the last quarter of 1905.

Fiscal year ending March 31st.	Common Stock Dividends.	Rate
	$ c.	Per cent.
1910..........	487,977 87	5⅓
1911....	3,026,859 25	32
1912..........	2,143,411 69	18⅓
1913..........	3,491,948 89	5⅓ per cent. on the stock of the old company plus 7⅓ per cent. on the stock of the reorganized company equal 9.18 per cent. on the latter.
1914..........	4,753,150 00	10
1915..........	3,803,937 50	12⅓
1916..........	13,234,953 00	23 plus stock dividend of 10 per cent.
Total	30,942,238 20	

Various factors have contributed to the success of later years. The general expansion of the nickel steel industry in Europe and America, the naval programmes of the great nations of the world, and the demand for ordnance and armament, together with a steady increase in the use of nickel for other purposes, have created a continuous and growing demand for nickel in large quantities. The enormous deposits of rich nickel ore in the Creighton mine have been a source of strength to this company, and it may fairly be added that the manner in which the business has been conducted at Sudbury and by the sales department has made the most of all favouring conditions. There has been constant education of the public in the use of nickel steel and nickel products. Plant and equipment are maintained at the highest point of efficiency, and the cost of production has been reduced by all modern improvements in appliance and operating methods. The company has not hesitated to expend large sums of money on experiments, and quite recently the sum of $266,000 was spent on an elaborate trial of the Knudson roasting process, which was not adopted in the end. More than $400,000 has been expended on experiments in smelting and treatment since 1902, and the whole industry has derived substantial benefit from the efforts of the Company to investigate all suggestions of improvement.

Out of its authorized capital, International Nickel Company made a first issue of $8,912,626 of 6 per cent. preferred stock, and $8,912,626 of common stock, and an issue in addition of $9,890,836.51 of first mortgage 5 per cent. bonds. After the further issue of common stock in June, 1910, already mentioned, the total issue of stock and bonds at that date stood at $10,391,836.51 of bonds, $8,912,626 preferred shares, and $11,612,626 of common stock. The bonded indebtedness had been reduced by payments under a sinking fund in September, 1912, to $7,900,153.88. All the outstanding bonds were then called at 110 and interest and were redeemed, and the bond mortgage for their security satisfied and discharged. The financial affairs of the original International Nickel Company were reorganized on the 5th of September, 1912, pursuant to the laws of New Jersey, by means of a consolidation of the company with Colonial Nickel Company, which had been incorporated in the previous July for that purpose.

The Reorganization of 1912

The new company, called "The International Nickel Company," the word "The" being added to its first corporate name, has an authorized capital of $62,000,000, of which $12,000,000 is in non-cumulative preferred shares, both as to dividend and as to assets in liquidation, and $50,000,000 is in common shares, all shares being of the par value of $100 each. In the re-organization, preferred stock in the original company was exchanged for a like amount of preferred stock in the new, and holders of common stock received 2½ shares in the new company for each share in the old. By agreement with Colonial Nickel Company $9,000,000 was provided in cash, which was used to retire the outstanding bonds. The stock issue to raise this fund was offered at par to shareholders in the new company, to a prescribed amount of their holdings. The net result was that the new corporation obtained all the assets of the old company and $9,000,000 in cash against an issue of $8,912,626 of preferred shares, and $38,031,500 of common shares. The unissued balance of either preferred or common stock must be first offered to shareholders of the company for subscription to the extent of their pro rata shares. On January 2nd, 1914, a stock subscription department was organized which gives employees an opportunity to acquire common stock of the company on liberal terms as to payment, which is similar in nature to the systems in force in a number of large corporations. A stock dividend of 10 per cent., payable 1st November, was authorized to common shareholders of record on October 15th, 1915. The last statement issued by the company as of December 31st, 1916, shows that the common stock then stood at $41,834,600, the preferred stock remaining at the original amount of $8,912,600, making a total share liability of $50,747,200. On January 18th, 1916, the par value of the common shares was reduced from $100 to $25. The shares of the company were listed on the New York stock exchange in September, 1915, and, as a result, the number of shareholders has been largely increased. At the end of the last fiscal year there were 7,145 shareholders. The Commission is informed that according to the latest record the holdings are distributed geographically as follows:—

Distribution of Shares

Country.	Preferred.	Common.
United States	85,180	1,606,885
Canada	1,924	46,017
Great Britain	835	17,120
France	279	1,543
Germany and Austria	256	453
Other Countries	652	1,366
Total	89,126	1,673,384

Profits and Assets

The accounts of the company make proper provision for depreciation and mineral exhaustion. A charge against earnings based upon the estimated life of the mines is made for each ton of ore smelted in order that their capital value may be amortized, and as long as the bonds were outstanding a substantial sinking fund

was provided for their annual reduction. The following is a statement of the surplus account of the company showing the annual profits for the several fiscal years since its incorporation, in all cases ending on the 31st of March.

	$ c.		$ c.
1903	559,148 65	1910	2,033,972 75
1904	204,102 05	1911	3,447,433 49
1905	224,379 18	1912	3,262,218 75
1906	380,579 34	1913	5,009,119 33
1907	1,189,499 04	1914	4,422,744 22
1908	995,915 80	1915	5,598,071 21
1909	774,894 52	1916	11,748,278 53
		Total	$39,850,356 86

The foregoing statement does not accord exactly in all cases with the annual reports of the "net profits" of the company for a larger amount, the explanation being that the surplus accounts properly deduct from the latter in these years a reserve to cover account of foreign constituent companies, and for depreciation of their properties. A comparison of the amounts received by the Canadian Copper Company from the International Nickel Company during the past five fiscal years on the sale of its matte from which the latter company derives the great bulk of its profits, will show that the arbitrary value placed upon the matte between the two companies as a matter of accounting does not represent its true value. The figures are as follows: $3,977,301.48 in 1912; $5,649,454.84 in 1913; $5,801,-198.87 in 1914; $4,482,362.37 in 1915; $8,041,457.74 in 1916.

The last public statement of the company in its consolidated general balance sheet of December 31st, 1916, gives its total assets as $61,230,813.58, made up as follows: Property, $44,622,675.86; investments, $2,995,243.94; inventories, $4,864,582.19; accounts receivable, $2,830,568.12; loans on call, $515,000.00; certificates of deposit, $2,030,000.00; cash, $3,372,743.47. The balance to credit of profit and loss account is shown as $4,933,257.61. Of the foregoing assets the last balance sheet (March 31st, 1916) of the Canadian Copper Company shows assets held by it in Ontario amounting to $10,872,124.31, of which $9,175,465.42 represents lands, buildings and plant exclusive of ore.

The Canadian Copper Company owns the following mines: Copper Cliff, Evans, Stobie, Crean Hill, Vermilion, Creighton, No. 1, No. 2, No. 3 (or Frood), No. 4, No. 5 and No. 6, and a one-third interest in the Chicago mine. It is at present operating only the Creighton, Crean Hill, Vermilion and No. 2. The company owns 10,615 acres of patented mineral lands, and also, in joint ownership with others, 1,083 acres and the surface rights in 3,880 acres, all in the district of Sudbury. It also owns 72,840 acres of undeveloped lands in the counties of Peterborough and Hastings, a legacy from the Anglo-American Iron Company, and is in process of acquiring additional areas in the township of Graham in the vicinity of the new roast yard, and of some lands on the banks of the Spanish river which will be flooded by the new power development at the Big Eddy dam.

The railroad to the Frood mine and all of the yard tracks, a total of about 13½ miles, are owned and operated by this company, which also owns the rolling stock and the village properties hereafter mentioned. The assets and holdings of the

Huronian Company, Limited, and of the "Orford Works" of the International, have been already summarized.

Expenditures in Sudbury

The cost of the properties of the Canadian Copper Company represented in the preceding statement of its assets is distributed as follows:—

Land, exclusive of ore reserves, $1,999,996.39; mining plant, $1,684,402.43; smelter, $3,818,952.26; railways, $635,870.50; dwellings, $817,881.24; hospital, $204,150.26; club house (uncompleted), $13,212.34. The club house has since been completed at a total cost of $63,580.45.

The aggregate pay roll for salaries and wages to March 31st, 1916, amounts to $16,257,449.80, which does not include wages paid by contractors on construction work. The salaries and wages paid during the calendar year 1916 were $3,567,549.37, and in addition an average of 200 men for the whole of the year were employed by independent contractors on construction work for the company. The freight paid in that year was $924,820.04, exclusive of the freight on the matte shipped to Constable Hook, which is paid at destination.

The following information has been furnished in regard to the municipal expenditures of the company:—

The municipality of the town of Copper Cliff was incorporated by a special Act in 1902. The population in May, 1916, is given as 4,064. Nearly all the area of 1,700 acres within the town limits and about 55 per cent. of the 730 dwellings are owned by the company. The company does not operate any stores, boarding houses or places of amusement itself. A well equipped hospital and a recreation club were built and equipped by the company at a cost of $204,000 and $63,580 respectively. All the street grading and a large part of the permanent street improvements have been done by the company directly, but all street maintenance is met by municipal funds. The water works and street lighting systems were installed by the company, no charge being made to individual users. A complete sewerage system, which will be paid for by the company, has been designed and is ready for construction. The company has paid to the town of Copper Cliff for taxes, $15,900 for the year 1913; $27,180 for 1914; $31,142 for 1915, and $38,247 for 1916. The total municipal taxes paid outside of Copper Cliff for these years respectively are $4,600, $6,977, $4,632 and $5,280.

The company built the Creighton road, seven miles in length, from Copper Cliff to the Creighton mine, at a cost of $25,800, and the Frood mine road, five and a half miles long, costing $40,000, both of which it also maintains.

Executive Officers of the Companies

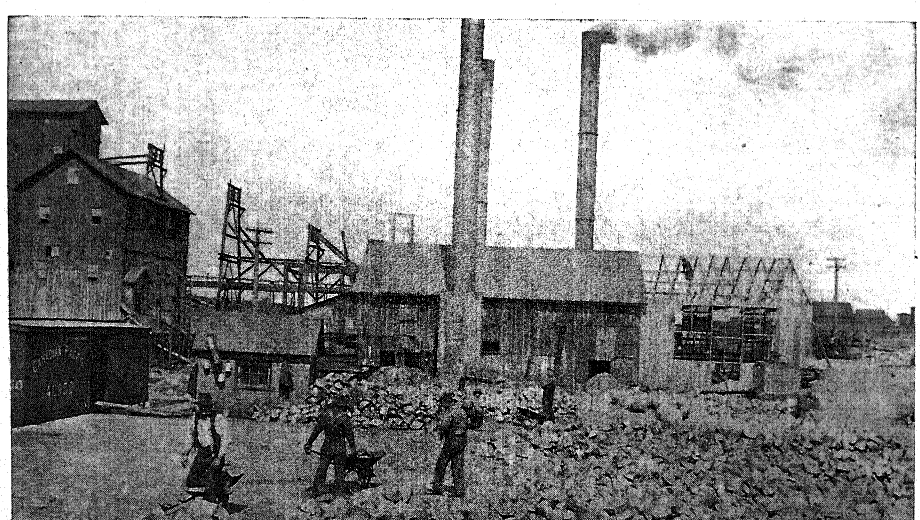
The executive officers of the International Nickel Company are: Ambrose Monell, president; Robert M. Thompson, chairman of the board; E. F. Wood, first vice-president; J. R. DeLamar, second vice-president; W. A. Bostwick, assistant to the president; Jas. L. Ashley, secretary and treasurer; Jas. W. Beard, auditor; Sullivan and Cromwell, general counsel. The directors are Robert M. Thompson, Ambrose Monell, E. F. Wood, J. R. DeLamar, William Nelson Cromwell, Alfred Jaretzki, S. H. P. Pell, Edmund C. Converse, William T. Graham, Willard H.

Brownson, Seward Prosser, W. A. Bostwick, James L. Ashley and W. E. Corey. Mr. Monell has been president of the company continuously since its incorporation, and there has been very little change during that time in the personnel of the directors, all of whom are men of prominence in the financial and business affairs of the United States. The late Mr. Duncan Coulson, president of the Bank of Toronto, was a director of the company for a number of years, and Mr. Charles Cassils, a capitalist of Montreal, has also been a member of the board. All of the present directors are Americans.

The administrative staff of the Canadian Copper Company in charge of its operations in this Province, is as follows: Arthur D. Miles, president; John L. Agnew, general superintendent; George E. Silvester, assistant to the president; John C. Nichols, superintendent of mines; William Kent, smelting plant superintendent; James W. Rawlins, metallurgist; J. T. Watson, electrical superintendent; Frank Ludlam, New York purchasing agent; R. N. Ladd, local purchasing agent; Frederick P. Bernhard, chief clerk; and E. T. Corkill, safety engineer.

A. P. Turner was the first president of the company after the formation of the International Nickel Company until the 11th of April, 1913, when he was succeeded by John Lawson, who occupied the office for a few months. A. D. Miles became president of the company on the 30th of August, 1913. The vice-presidents during that period have been F. S. Jordan, from June 7th, 1902, to December 1st, 1912; John Lawson, who took his place until April 22nd, 1913; B. G. Slaughter from that date to the 14th of October, 1914, when F. S. Jordan was again appointed to the office, which he still fills.

In view of the interest that has been taken in the destination of Canadian nickel, the International Nickel Company has been good enough to comply with a request for information on the subject, by submitting the following statements covering all shipments of its metallic nickel to different countries for the past ten years preceding the war, and also during the war for the three several periods given.



Canadian Copper Company, Copper Cliff. Matte yard, West Smelter, as it was in 1902. The buildings were destroyed by fire June 14th, 1904.

Shipments of Metallic Nickel for Ten Years Before the War

(In pounds)

Date.	Shipments.	United States.	Canada.	Great Britain.	Germany.	France.	Italy.	Russia.	Austria.	Marine Losses and Adjustments
1905	14,086,025	6,428,278	....	4,348,004	2,917,621	392,122	....	....	....	....
1906	14,022,511	5,802,387	....	3,460,568	3,885,675	336,124	537,757	....	....	....
1907	13,528,033	6,246,662	....	4,149,254	1,720,549	963,469	448,099	....	....	....
1908	11,965,948	4,382,083	....	1,916,492	4,826,439	381,546	459,388	....	....	....
1909	19,668,655	8,519,409	....	2,299,410	7,168,097	1,345,535	336,204	....	....	....
1910	24,138,588	11,150,581	....	2,841,184	8,182,525	1,247,336	716,962	....	....	....
1911	26,714,205	8,412,500	....	4,366,640	7,957,469	4,588,684	1,388,903	....	....	....
1912	33,624,982	11,452,880	26,000	7,258,813	8,519,222	4,909,749	1,456,205	....	....	2,113
1913	33,876,214	11,088,222	12,508	8,399,827	10,869,260	3,330,611	693,211	73,488	403,115	5,972
1914 Jan.-July inc.	20,468,602	5,430,239	25,882	5,740,685	4,949,750	3,079,182	581,609	186,626	470,443	4,186

Shipments of Metallic Nickel Since War Began

(In pounds)

Country.	Period from Aug. 1, 1914 to July 31, 1915.	Period from Aug. 1, 1915 to July 31, 1916	Period from Aug. 1, 1916 to Dec. 31, 1916
Great Britain	14,465,234	14,932,583	6,400,653
France	2,824,936	3,224,919	1,075,200
Russia	5,967,392	5,689,600	4,480,000
Italy	2,524,612	2,043,000	851,200
Japan	515,216	470,400	....
Australia	22,400	....	67,200
Mexico	3,584	....	....
Denmark	....	38,080	....
Spain	....	112,000	2,240
China	....	4,480	....
Marine Losses	794	....	....
Canada	130,636	99,212	54,750
United States	17,513,505	25,945,839	15,400,432
Total	43,968 309	52,560,113	28,331,675

Refinery in Ontario

The announcement in the public press that, since the appointment of the Commission, the International Nickel Company had expressed its intention of establishing a refinery at some suitable point within the Province has been received with peculiar satisfaction. The Commission is gratified to report that all necessary arrangements for that purpose have been concluded by the company, and has much pleasure in submitting the following report from the company as to the progress made towards the construction of the works at the present time (February 5th, 1917). The report from the company is as follows:—

The site selected by The International Nickel Company of Canada, Limited, for its Canadian nickel refinery is at Port Colborne, Ontario, somewhat to the eastward of the entrance to the Welland canal. The site consists of approximately three hundred and fifty (350) acres in extent, with a frontage on Lake Erie of approximately one (1) mile, this frontage immediately adjoining the Lake Erie frontage of the Canadian Furnace Company. Transportation facilities for the refinery will be provided by direct connection with the Grand Trunk railway, a branch line of which passes the northern boundary of the refinery site. The position of the site with respect to the Welland canal is such that recourse may also be had to transportation by water for such commodities as will be utilized in the refinery in large quantities, such as coal and coke, and where, owing to their points of origin, such water transportation may be deemed advisable.

This site was selected and options taken upon the property about the first of August last after examination of many possible sites in various parts of the Dominion. Preliminary engineering work, and surveys and testing of the suitability of the sites for foundation purposes were then proceeded with, concurrently with the examination of title, and certain necessary legalities with the local councils were arranged. Title was taken to this property early in October, and active construction on the ground immediately commenced. After the preliminary engineering work had shown the suitability of the site for the plant, a contract was entered into with The Foundation Company, Limited, of Montreal, which company has charge of the entire piece of construction. This company, in conjunction with the operating and engineering departments of The International Nickel Company, engaged actively in the preparation of the general and detailed plans of plant buildings and equipment, and by so doing, were in position by the time title to the property had been taken, to immediately commence construction and to let contracts for the more important building materials and equipment, on which delayed deliveries were expected.

The estimated cost of the completed refinery will be approximately $4,000,000, and it is expected that the refinery will be completed and ready for operation in the autumn of 1917,

provided no greater shortage of labour is experienced than that already apparent, and that the sub-contractors will be enabled to fulfil their promises of delivery.

On the construction work now in active progress, about four hundred (400) men are being employed, and preparations have been made so that by next spring employment will be available for about one thousand (1,000) men on this construction. The railroad connections, sidings and yard tracks, in which there are about 18,000 feet of track, requiring four hundred (400) tons of rails, together with the grading, amounting to 270,000 cu. yards, are well under way. The excavating for foundations of buildings is well along, and many of the foundations of the permanent structures are already in place. This will ultimately amount to about 80,000 cubic yards.

The basis of the lay-out of the refinery provides that the buildings are so placed that various stages of the process are segregated, and the economical handling of the labour and materials is obtained, liberal allowance being given to provide for future extensions. Practically all of the buildings are of steel and brick construction, 10,000,000 pounds of structural steel being estimated for this work. It is to be noted that this structural steel will be supplied, fabricated and erected by the Dominion Bridge Company of Montreal. There will be 51,000 tons of concrete for building foundations, and 350,000 square feet of forms for concrete work. Contracts have been placed for the 6,000,000 bricks required, these being manufactured in the Hamilton district. The great bulk of general supplies is being purchased in Canada, and only under special circumstances are materials for construction and process equipment being imported.

The two main refinery stacks of radial brick construction will be amongst the largest yet built, being 350 feet high and 12 feet diameter at the top, the base of each of these stacks being of massive concrete construction 40 feet by 40 feet.

Special attention has been given to lighting and ventilation, there being 130,000 square feet of windows in the main buildings and 300,000 square feet, or over seven (7) acres of roofing. The workshops are to be most complete and equipped with modern machine tools and labour saving devices. The initial output of the refinery will be on the basis of 15,000,000 pounds of refined nickel per annum, but the company, in the design of the plant and process equipment, have kept in view the possibility of this output being doubled or even quadrupled, within a few years.

The operating force, on the initial basis of 15,000,000 pounds of nickel per annum, will be about 400 men, and the company has reserved a site 300 feet deep by 4,000 feet long to provide for housing of employees. An attractive club house and recreation hall, and a large residential club for single men, are now in course of construction, but in view of the building of houses in the vicinity by local interests, the company has decided not to proceed with building of workmen's cottages until next year, at which time any requirements not arranged for will receive attention.

In operating the nickel refinery, a large number of products come into use, but apart from the large tonnage of copper-nickel matte, which will be supplied from Northern Ontario, there will be bituminous coal, coke, cordwood, fuel, oil, nitre cake, charcoal, silica rock, salt, soda ash, nitrate of soda, sulphuric acid, fire clay and fire brick, estimated annually at about 100,000 tons.

A subsidiary company called "The International Nickel Company of Canada, Limited," was incorporated under the Dominion Companies Act on the 25th of July, 1916, with comprehensive powers to produce, manufacture, refine, smelt and deal in, nickel, copper, iron, steel, manganese, cobalt, coal, coke, platinum, palladium and other metals, minerals and mineral substances, and other incidental objects. It is understood that the Ontario refining works will be operated by this new Canadian company, and that all the assets and properties connected with them will be vested in it.

The Mond Nickel Company, Limited

The Mond Nickel Company, Limited, is the only other company at present producing matte and conducting operations on a large scale in Ontario. It is a British company, and was incorporated under the Imperial Companies Act on the 20th September, 1900. By a voluntary liquidation the company was reorganized under the same statute, and the new company was incorporated on the 22nd of July, 1914.

Refining Process Precedes Ore Supply

In striking contrast with the Canadian Copper Company, the Mond company possessed a process for refining nickel before it had ore, and came to Ontario to procure the ore to utilize its process. This unique process, which is known by the name of the inventor, and is fully described elsewhere, was originated by the distinguished scientist, Dr. Ludwig Mond, F.R.S., in 1889. After laboratory demonstration, an experimental plant on a small scale was put up at Smethwick, near Birmingham, at which it was developed for industrial purposes. The process was first offered to English steelmakers, and, as mentioned before, it was investigated and declined by the Canadian Copper Company in 1895. It is reported that the proprietors had the opportunity at this time of purchasing the entire holdings of the latter company in this province.

The success of the process having been definitely assured, Dr. Mond began to look about for ore, and finally decided in favour of the Sudbury district. Considerable time was spent in looking over the ground, and what was then known as the McConnell property, in the township of Denison, was purchased in the summer of 1899. Development work was pressed forward at the mine; roads were built; a roast yard levelled and prepared, and in February, 1901, the mine, thereafter known as the Victoria mine, was ready for operation. A smelting plant of the most modern type was installed on the Sault branch of the Canadian Pacific Railway, 22 miles west of Sudbury, and with the accessories of offices, storehouses, shops and comfortable dwellings, formed the village site of "Victoria Mines." The plant was steam driven and had a capacity of 60,000 tons of ore a year, but it was remodelled for electric power in June, 1909, and its capacity increased to 140,000 tons. A bessemer matte containing 80 per cent. nickel and copper in nearly equal parts was produced, but for reasons connected with the early operation of the refining plant in Wales, the smelter was shut down, except for a few months in 1903, from December, 1902, to the end of 1904. The ore was brought from the mine to the smelter by an aerial tramway, two miles in length. The roast yard was on the line of the tramway, about midway between the mine and the smelter.

The refining works were located at Clydach, near Swansea in Wales. The selection of this point was determined by the advantages of the locality in the way of anthracite, cheap chemicals, experienced labour, sea transport, and the facilities for shipping sulphate of copper to the vine-growing countries of the Mediterranean. The site covers 45 acres, and was acquired in freehold with the underlying coal. The whole of the matte produced in Ontario is refined at the Clydach refinery.

From 1901 until 1913 the company conducted its smelting at Victoria Mines, but with the final perfection of its refining plant, and good prospects of increasing business, the limitations on the Victoria Mines site, which was not adapted to further expansion, were felt to hamper the company's operations. There was railroad connection with but one line, and after the purchase of additional mines, the smelter was found to be too far from the centre of the ore supply.

New Smelting Plant at Coniston

After careful investigation of the whole district, a site at Coniston, which is eight miles east of Sudbury, was finally selected as the location of the Canadian

plant. It is on the main line, both of the Canadian Pacific and Canadian Northern railways, and is served by the Toronto branch of the Canadian Pacific Railway which joins the main line a little farther west. The site comprises 3,700 acres, and the greater part of the land now occupied by the works and village was cleared from the bush. The excellent new plant now in use was completed and smelting commenced on the 15th of May, 1913.

The company's village is situated immediately north of the C. P. R. main line, about three-quarters of a mile from the smelter. In the development of the village over two miles of streets were graded, and over two and a half miles of sidewalk built. Electric street lighting was provided, and drainage, water supply and fire systems constructed. The water supply is pumped from the Wanapitei river, a distance of over two miles, and one and a half miles of pipe lines were laid, in addition, for local supply. The water system, which serves the plant en route, was installed at a cost exceeding $50,000. Two three-roomed schools were built and presented by the company to the school sections, and the company also built, at its own expense, a fire-hall, a combined municipal building and jail, and a customs office. Up to the present none of these several utilities has been municipalized. The total expenditure by the company on Coniston village is said to amount to $260,000. Similar expenditures, though on a smaller scale, have been made by the company at the Levack, Worthington, and Garson mines, making a total disbursement to date for these purposes of $400,000.

Company's Mines and Power Plants

The company gets its ore from the Garson, Worthington, Levack, Victoria and Kirkwood mines, all of which are owned and worked by it, and from small purchases which have been made from the Alexo, Mount Nickel and Howland mines. It is curious that with its excellent process and splendidly equipped plants for both smelting and refining, the company should have had some concern for a time in regard to its supply of ore. Large sums have been spent on exploration and survey work in the district, in the course of which a number of properties, including the Murray mine, have been examined and declined. The Garson mine, originally known as the Cryderman mine, one mile from Coniston, was bought in 1907. This mine has up to the present been the chief producer of ore for the company, with an output to December 31st, 1916, of 987,571 tons, as against 675,735 tons from the Victoria. The Victoria has the deepest shaft in Ontario at its No. 1 mine which is now at a depth of 2,618 feet vertically. For the past ten years this mine has been shipping about 4,000 tons a month, which it is now exceeding. In 1910, the property known as the Frood Extension, adjoining the Frood mine of the Canadian Copper Company, was bought. An important source of ore has been opened up in the Levack mine, on the northern range, bought in 1913 from the well-known pioneers, Messrs. Tough, Stobie and McConnell. Although development and equipment were started only within the last two years, the output is already between 5,000 and 6,000 tons monthly. Diamond drilling has proved reserves in this property of 4,500,000 tons, and the company is thus assured an ample supply of ore for many years to come. The total production of all mines to December 31st, 1916, was 2,053,574 tons.

The company is well supplied with power from its own power plant at Wabageshik on the Vermilion river, and from the Wahnapitae Power Company. An additional plant has recently been completed at Nairn Falls on the Spanish river, which was ready to supply power in February, 1916. The electric power obtained from the plants owned by the company is distributed through its properties over a common transmission line about 90 miles in total length. The entire power system is operated by the Lorne Power Company, a subsidiary of which all the shares are held by the Mond company. The investment in water powers and transmission lines is over $1,100,000.

The company owns and operates approximately 21 miles of railway, which it has built in connection with its mining and reduction works. The total cost, to date, for construction, has been about $300,000, and the company has, roughly, $150,000 invested in rolling stock. Of the total mileage the company operates about three-quarters with its own engines and crews.

The Refinery at Clydach

The works and metallurgical practice of the company are described in detail in the Chapter on Refining Processes. It may be observed here, however, that the plants, both at Coniston and Clydach, are excellent in layout, construction and equipment. The refining plant in Wales is admirable in every detail. It operates a process entirely unlike that anywhere else employed, it is largely automatic, and in smoothness of working will compare favourably with any metallurgical works in Great Britain or elsewhere. The company provides a commodious club for its employees and a subsidiary company owns a number of attractive cottages for housing. A new unit, identical in type with those already in use, has recently been added to the plant and is now in operation. This will permit an output of 5,000 tons of metallic nickel a year, in addition to the copper sulphate, and a large amount of nickel sulphate produced annually. No metallic copper is produced. There is space adjoining the new unit for two units of similar capacity, and room elsewhere on the site for further units, which could bring up the capacity of the plant to 10,000 or 12,000 tons of nickel per annum. The copper sulphate is used to prevent blight on vines in the vine-growing countries of southern Europe. This is an important and profitable branch of the business, and the necessity for quick transport in the short season during which it is required is one reason urged by the company against the location of the refining plant on this side of the Atlantic. Another is the fact that copper sulphate is more than three-fourths water, and that to pay freight charges for carrying so much water across the Atlantic would so increase the cost as to close the markets for the company's product. About 1,000 hands are employed in Wales in normal times, and about 1,700 in Ontario.

The nickel produced by the Mond process is of exceptional purity, and this very fact was urged against its use for ordnance and armour purposes. All objections of that nature, which were wholly matters of trade prejudice, have fortunately disappeared, and there is now a decided preference among British users in favour of Mond nickel for many special purposes.

The Company's Finances

The authorized capital of the original company was £600,000, divided into 50,000 cumulative preference shares of £5 each, 300,000 ordinary shares of £1

each, and 50,000 deferred shares of £1 each. The preference shares carried 7 per cent. In 1908 the authorized capital was increased to £850,000 by providing for the issue of an additional 50,000 £1 cumulative preference shares, of which £30,000 was issued. This raised the issued capital to £750,000, of which £400,000 was preference shares, on which the stipulated dividend of 7 per cent. has always been paid. The share capital remained in this position until the fiscal year ending April 30th, 1914, during which the remaining 20,000 preference shares were offered for subscription to debenture holders and shareholders, and allotted at a premium of 15 per cent. In July, 1911, £250,000 of an authorized issue of £375,000 of 5 per cent. first mortgage debenture stock was allotted to provide further capital for the new site and smelting works in Ontario. In November, 1912, the unissued balance of £125,000 of this stock was offered to stock and shareholders at a premium of 3 per cent. and was fully subscribed.

The assets of the company are given in the balance sheet for the fiscal year ending April 30th, 1913, at £1,638,316. It may be assumed that the large increase in capital expenditure required for the provision of the new site and works in Canada and the purchase of the Levack and other properties, was the principal cause for the reorganization of the capital of the company, pursuant to the Imperial Companies Act, which was effected according to resolutions passed at an extraordinary general meeting of the company held on the 18th of June, 1914. The reorganized company was incorporated on the 22nd of July of that year.

The authorized capital of the new company is £2,400,000, consisting of 500,000 7 per cent. cumulative preference shares, 1,000,000 7 per cent. non-cumulative preference shares and 900,000 ordinary shares, all of £1 par value each. In the reorganization, five 7 per cent. cumulative preference shares were exchanged for one similar £5 share of the old company, and one 7 per cent. non-cumulative share and one and a half ordinary shares of the new company, for one ordinary share of the old company. The deferred shares which had received such phenomenal dividends, were abolished. The whole of the cumulative preference shares and of the ordinary shares, together with 480,000 of the non-cumulative preference shares, have been issued, making an issued share capital of £1,880,000. Debenture stock has been issued, in addition, amounting to £875,000, which makes an existing share and stock liability of £2,755,000.

Of this amount, £180,000 of the non-cumulative preference shares and a new issue of £500,000 6 per cent. redeemable debenture stock, were offered for subscription in 1914, to meet contingencies that might arise from the outbreak of the war; and it is a tribute to the good standing of the company that the issue for the debenture stock was over-subscribed.

The balance sheet for the fiscal year ending April 30th, 1916, shows assets amounting to £3,679,888; mines, freehold and leasehold land, houses and smelting works in Ontario are valued at £1,536,278; lands, freehold and leasehold property and the refining works at Clydach, Wales, at £598,194.

The Canadian assets do not include the properties held by the power company, the Lorne Power Company of Ontario, which represents the substantial part of the item of £280,786 for shares in associated and other companies.

The company owns the Victoria, Garson, Levack, Worthington, Blezard, Kirkwood, North Star and Little Stobie mines, in addition to a large acreage covering

undeveloped properties. The Bruce copper mines have lately been added to its holdings, the ore being used as a flux in the converters. Drilling is now being done at the Blezard mine, which has not been worked for 23 years. The investments in power plants and properties, railways and village sites have already been given.

Expenditures and Dividends

During the past four years the total expenditure of the company in Canada is given as $13,300,000; the expenditure on operation alone during the calendar year 1916 being $2,750,000. The total wages paid in Canada to December 31st, 1916, is $7,978,000. The freight paid to railways during the year 1916 was $695,000.

Very large sums have been spent in Canada, in addition, on exploration work, by diamond drilling and magnetic surveys, and upon various experiments in connection with treatment of the ore, which are said to approximate one million dollars.

The development of the company's business will be shown by the following summary of profits and dividends in recent years:

All dividends on the preferred shares have been paid.

The first dividend on the ordinary shares was declared in 1905, when a dividend of 7 per cent. was paid. In 1906 the ordinary shareholders received a dividend of 10 per cent., which was followed by dividends of 12½ per cent. in 1907, 15 per cent. for each of the three years, 1908, 1909 and 1910, and 16½ per cent in 1911 and 1912. In 1913 and 1914 the dividends to ordinary shareholders were 21¼ and 35 per cent. respectively.

For the two fiscal years since the reorganization of the company, the dividend has been at the rate of 20 per cent. on the ordinary capital of £900,000.

Deferred shares, amounting to £50,000, paid 18 per cent. in 1906, 33 per cent. in 1907, and 48 per cent. for each of the next three years, 1908, 1909 and 1910, and 55½ per cent. in 1911 and 1912. In 1913 they received a dividend amounting to 84½ per cent., and in 1914, the last year of their existence, of 168 per cent. All dividends are subject to income tax. The company's fiscal year ends on 30th April.

Under the articles of association, 5 per cent. of the profits for the year, is distributed to the board as directors' fees.

The company has always made prudent provision against contingencies by a substantial reserve and a good balance forward for the ensuing year. The balance sheets show net profits as follows:

For 1910, £120,112; 1911, £148,214; 1912, £154,364; 1913, £201,102; and for 1914, on the original capital of £850,000 and £375,000 of debenture stock, £261,146. The profits of the new company on its operations for the two fiscal years of its existence are £300,296 for 1915 and £322,589 for 1916.

A very large increase appears in the balance sheets during the war, in connection with the stocks of ore, raw materials and products on hand, which have been accumulated to enable the company to continue its output of refined nickel in the event of any interruption in ocean traffic. The stock in reserve for this purpose amounted in 1915 to £607,015, and in 1916 to £756,050. The importance to the Empire of this wise precaution is obvious, and the services

rendered by this company in this and other material respects as a British company during the war, give great force to the contention that the whole of the operations connected with the production of refined nickel should be conducted and completed within the Empire.

War Taxation

The reserves of the company are invested in the Imperial War Loan, and substantial contributions have been given to Canadian and English organizations for different forms of war relief. The company is a controlled establishment, and is liable accordingly to pay the heavy taxation imposed by the war legislation of the Imperial Parliament. The excess profit tax for the year 1915, which is retroactive, amounts to £37,000. Expenditure for allowances to families of employees on active service, war subscriptions and war bonuses, together with this tax, amount to £56,866 during the year.

Although its employees and staff are exempt from military service, as operatives of a controlled establishment, a large percentage have joined the colours since the outbreak of the war. The company keeps open the position of all these men and pays them half wages, while those who are tenants of the company's houses are relieved from the payment of rent while on service. Employees on the staff are paid the difference between their salaries and the pay they receive on service. The Commissioners would be sorry to think that the company has been handicapped in any way by the fact that it is a British company, and subject accordingly to special burdens resulting from the war, from which its competitors are free.

In view of the interest that has been taken in this country in the association of the Canadian nickel companies with the metal broking firm of H. R. Merton & Co., of London, by reason of its reported affiliation with enemy concerns, Sir Alfred Mond explained the connection of his company with Messrs. Merton & Co. in his interview with the Commissioners, of which a report will be found in the Appendix, as follows:

Messrs. Merton & Co. acted as metal brokers to the company (as they apparently did for all the companies selling nickel in Great Britain). They never had any control or interest in the capital, policy, finance or manufacture of this company. All the products of the company other than nickel, such as copper, sulphate, nickel salts and the precious metals residue, have been dealt with by the sales department of the company, without the intervention of any other company or firm. These products, in tonnage and value, represent the largest part of the company's output, and in the year 1913, preceding the war, of the company's total sales only 17 per cent. were made through the metal brokers, and in 1914, 28 per cent. The company had always reserved to itself the whole of its business with the British and Dominions' governments.

The total shares and debenture capital was held in April, 1916, by 4,729 shareholders or stockholders, of which only .61 per cent. in value was held by thirteen alien enemies, residing in Germany and Austria.

The executive officers of the company in Canada are: Manager, C. V. Corless; mine superintendent, O. Hall; superintendent of reduction works; J. F. Robertson; chief engineer, W. L. Dethloff; cashier, W. A. McDonnell.

The directors of the company are: Robert L. Mond, Sir Edmund Walker, Sir Robert A. Hadfield, the Right Hon. Ellis Griffiths, M.P., Carl Langer, Robert Mathias, Bernard Mohr, Emile S. Mond, and Saxton W. Noble.

The Right Hon. Sir Alfred Mond, Bart., M.P., who has been recently appointed president of the Board of Trade and a member of the Imperial government, has been the chairman of the company since the death of his father in December, 1909. Upon his resignation from the Board, in consequence of taking office in the Government, Mr. Robert L. Mond was elected Chairman in his place. The late Sir George Drummond was one of the early directors in the original company, and continued in that office until his death. Sir Edmund Walker succeeded him as the Canadian director. The Right Hon. Ellis Griffiths, M.P., late Under-Secretary to the Home Office, and Sir Robert A. Hadfield, Chairman of the firm of Hadfields, Ltd., of Sheffield, were added to the Board at the last general meeting.

The Alexo Mining Company, Limited

This young Canadian company is the only other company at present conducting active operations in Ontario in the production of nickel. It is engaged in mining nickel ore at the Alexo mine, situated in Dundonald township in the district of Timiskaming, three and a half miles southeast of Kelso, on the T. & N. O. railway, and more than one hundred miles distant from the nearest point of the northern range of the Sudbury deposits. The mine was discovered by Alexander Kelso, in February, 1908, and the directors and shareholders are composed entirely of the original members of the syndicate which staked the property. Some stripping was done in 1908, but with the exception of diamond drilling, no further work was done until the winter of 1912, when the late manager, E. F. Pullen, took out 1,862 tons from surface pits and from a shaft which had been sunk on the vein. This ore was shipped to the Mond Nickel Company at Victoria Mines, and an arrangement was subsequently made by which the output is sold to that company. Shipments have been made regularly since that time, with the exception of a short interval following the outbreak of the present war.

The company was incorporated under the Ontario Companies Act on January 8th, 1913, with an authorized capital of $40,000, composed of 40,000 shares of a par value of $1.00 each, of which 30,005 shares have been issued. In 1913 a small steam plant was installed, and the ore mined from an open pit and a short drift at the bottom. In 1914 drifts were run from both ends of the open cut, from which the tonnage of that year was taken. Drifts have since been run from the 125-foot level, and the shaft continued to a depth of 200 feet.

The ore is teamed three-quarters of a mile to the mine siding on the Porcupine branch of the T. & N. O. railway. During 1916, 8,288 tons were raised, making the total output from the mine to the end of that year 34,650 tons. The company employs an average of 20 hands, and its operations are confined entirely to mining its ore.

The company's assets consist of 600 acres of mining lands, buildings, plant, accounts receivable and cash on hand, of a total value of $69,473.96. There is no bond issue or preference stock, and only a few small dividends have as yet been declared. The wages paid to date amount to between $60,000 and $70,000.

The officers of the company are as follows:—President, Major E. F. Pullen; vice-president, G. F. Hanning; secretary-treasurer, H. N. Roberts.

The directors are:—Major E. F. Pullen, G. F. Hanning, Alex. Kelso, Major C. W. Allen and Captain Frank Pullen, who are five out of the seven shareholders. William Anderson is at present manager of the company. Major Pullen, Major Allen and Captain Pullen are on active service.

British America Nickel Corporation, Limited

Within the last few weeks the British America Nickel Corporation, Limited, a strong British-Canadian company, which is controlled by the Imperial government, has broken ground for the construction of large smelting and refining works near Sudbury for the production of refined nickel. The operations of the company, as contemplated at present (Feb. 1st. 1917), will be unique in the history of the industry in the important particular that the mining, smelting, and refining of its ore will all be conducted not only within the Province, but within the Sudbury district; and for this and other special reasons the progress of its undertaking has been followed with unusual interest.

The company owns approximately 17,600 acres of mineral land which include the following copper-nickel properties, namely: The Murray, Elsie and Lady Violet mines; the Gertrude mine; the Whistle and Wildcat mine; the Victor and Blue Lake group; Nickel lake; and what are known as the Falconbridge properties. All its nickel holdings were bought from the Booth-O'Brien company called The Dominion Nickel-Copper Company. It has acquired the exclusive rights for North America in the electrolytic process for producing metallic nickel, known as the Hybinette process, which the company will use for refining the Sudbury ores. This process, which is fully described in Chapter IX, has been in practical operation for some years at the works of the Kristianssands Nikkelraffineringsverke at Kristianssands in Norway. It was first employed in America at the plant of the North American Lead Company at Fredericktown, Missouri, in connection with a lead-copper-nickel property there, and it was indirectly through this connection that the promoters of the present company first got in touch with its owners for the subsequent purchase.

The late Dr. F. S. Pearson, the well-known financier of New York and London, took an active part in the protracted negotiations and series of transactions which finally resulted in the purchase of all the Ontario assets of the Dominion Nickel-Copper Company, and of the rights in the Hybinette process. In September, 1912, an option was obtained on all the properties and assets in Ontario of the latter company, which included a short line of railway called the Nickel Range railway, for a large purchase price, of which $1,000,000 was payable in cash. After considerable exploration work which established new ore bodies, especially on the Murray-Elsie properties, the option was taken up, and an agreement for purchase concluded between the owners and Pacific Securities, Limited, an office company incorporated under the Dominion Companies Act for the purposes of the transactions in hand. It is said that $800,000 was spent in diamond drilling on the various properties.

In the meantime the Hybinette electrolytic process had been carefully investigated under option by a number of experts who studied its working in the refinery

in Norway, and reported favourably upon it as an efficient process for Sudbury ores adapted to operation in Canada. By agreement, dated December 12th, 1912, with the Norwegian owners, the exclusive rights for North America in the patents and processes were granted to Pacific Securities, Limited, and on February 27th, 1914, all the rights so obtained were transferred to this company.

The company is incorporated by letters patent under the Dominion Companies Act, dated July 2nd, 1913, with full powers for all primary and incidental purposes connected with the mining, treatment, marketing and sale of ores, minerals, metals and their products, and an authorized capital of $20,000,000. The whole of the capital has been issued, and $6,000,000 of 6 per cent. first mortgage bonds, secured by a mortgage to National Trust Company, Limited, has also been issued. Of an authorized issue of $10,000,000 of 6 per cent. debenture stock, $3,500,000 has in addition been issued to date, making a total bond and stock liability at present of $29,500,000. A special Act of the Dominion Parliament (4-5 George V, cap. 132) empowers the company to issue share warrants and redeemable preference shares. A second Act of 1916 (6-7 George V, cap. 57) authorizes a board of twenty directors, if desired, and provides that the majority of directors shall be British subjects. No share warrants or preference shares have as yet been issued.

The promoters were engaged in financing the enterprise in London when Dr. Pearson was drowned on the Lusitania in May, 1915. Dr. Pearson's death and the financial stringency following the outbreak of war arrested progress for a time, but the negotiations in London were subsequently resumed by his associates and brought to a successful conclusion. The company was so fortunate as to secure the material co-operation of the Imperial government, in the form of substantial advances in money and a long term contract for a large annual supply of nickel from its Canadian works. It is understood that $3,000,000 of bonds, or one half the total issue, and $14,500,000 of the $20,000,000 of the issued capital stock are held in trust by the Public Trustee for the Imperial government. The shareholders of the Kristianssands company, which has been operating the Hybinette process in Norway, have considerable holdings of the stock, and, with this exception, the whole of the capital stock and of the securities is held by British subjects.

Locating Works at Murray Mine

The first intention of the company was to follow the plan of its vendors, and build its smelter at the Whistle mine as the main source of its ore supply. The prospecting of the Murray properties disclosed such large reserves reported at 8,500,000 tons of ore, which is said to be increasing in quantity and improving in nickel contents with depth, that it was decided to locate the smelter plant at this point, which has other advantages for the purpose. There is railroad connection with the main line of the Canadian Pacific railway and with the Algoma Eastern railway, the benefits which will be derived from the proximity of the town of Sudbury. Until quite recently, the company contemplated locating its refinery at some other point in the Province convenient to electric power, probably in the Welland or Niagara district, but it has now been decided to build both the smelter and refinery side by side on a site about a mile south of the Murray mine. There is a force of men at work preparing the site for this plant, for which the details are

now (February 1st, 1917), being drawn. The specifications and estimates for buildings and machinery are being prepared, and tenders will be called for shortly. The critical question of power supply has not been definitely settled at this date, but the officials of the company have had conferences with the municipal council and board of trade of Sudbury, from which they report that encouraging advance has been made towards procuring the necessary power from the French river through the Ontario Hydro-electric Commission. The negotiations contemplate the supply to the company of 8,200 horse power for the first unit, with further supply to be provided within a year from the commencement of operations for the additional units that will be required. If the necessary arrangements to that end are concluded, the company will rely on the town of Sudbury to supply the housing for its employees, and provision has already been made for transporting the operatives from the town to the mine and plant when operations are commenced. There are 50 men working at the Murray mine, in which the shaft is down 700 feet, and when the limit of the present equipment is reached, a hoisting engine driven by electricity, together with the rock house and sorting plant, for which plans have been prepared, will be installed. It is said that diamond drilling has proved approximately 12,000,000 tons of nickel-copper ore on the several properties, and that when the plant is completed the works and properties of the company will represent an investment of $10,500,000. The amount to be expended in plant and machinery is given as between $4,000,000 and $5,000,000 and the company expects to produce 6,000 tons of refined nickel a year.

The officers of the company are as follows:—President, James H. Dunn; vice-presidents, J. Frater Taylor, W. A. Carlyle; secretary-treasurer, W. H. Coade; general manager, E. P. Mathewson; directors, Alan Garret Anderson, H. Malcolm Hubbard, London, England; Admiral Borresen, Sam Eyde, V. N. Hybinette, Norway; E. R. Wood, J. S. Lovell, Robert Gowans, R. Home Smith, Toronto. The president is a Canadian capitalist residing in London, England. Mr. Carlyle, late professor of metallurgy in the Royal School of Mines in London, was for some time manager of the Rio Tinto copper mines in Spain. Mr. Mathewson was manager of the reduction works of the Anaconda Copper Mining Company until his connection with this company. Both are Canadians by birth, and Canadian metallurgy is fortunate in receiving this accession of administrative and technical skill.

Other Operating Companies

The history of the several companies that have been engaged at different times in the past in the mining or treatment of Sudbury nickel ores, has been largely anticipated in Chapter II, which deals with the history and development of mining. Their respective activities are mentioned there in connection with the several properties which they have worked, and they have been sufficiently described by Dr. Barlow and Dr. Coleman. Their operations have in all cases entirely ended, and their history is of little interest, except in its occasional bearing upon later developments of the industry.

H. H. Vivian and Company

The great firm of H. H. Vivian and Company, of Swansea, Wales, was one of the first companies to undertake practical operations in the district. The Murray

mine on the main line of the C. P. R., about three miles west of Sudbury, which had developed from the cutting of the right of way, was prospected under option in the summer of 1889, and was bought from the patentees in October of that year. A smelting plant was put up near the mine which was ready for operation in the fall of 1890, and a bessemer matte was produced containing between 55 and 65 per cent. ~~of nickel and copper, which~~ was shipped to Swansea and there refined. The company also owned the property known as the Lady Violet mine, about a mile and a half southwest of the Murray. Some preliminary development work was done on it and temporary buildings erected, but the supply of ore was obtained from the Murray mine, at which ample provision was made in the way of plant and accessories for operations on a large scale. Mining and smelting were carried on until the summer of 1894, when all the works were shut down, and they were never operated again by the Vivians.

The advent to the district of this celebrated metallurgical firm of world-wide reputation, whose resources and experience promised vigorous and skilful development, was naturally regarded as an event of great importance to the industry. Previous writers agree that the withdrawal of the Vivians after sustaining a considerable loss had a depressing effect upon it for some time. It is understood that the failure of the undertaking was mainly due to defects in management and lack of co-ordination between the local executive and the head office in Wales. Dr. Barlow says[1] that "from the very outset a seeming lack of energy, and often even of ordinary business ability, on the part of those who had control of the work, was a subject of common remark, being in marked contrast to the alert methods characterizing the operations of the rival corporation, the Canadian Copper Company. This was evident in almost every department of the work."

It should be borne in mind, however, that as shown elsewhere, the general conditions of the industry at this time were bad. The production from the new field at Sudbury by three operating companies had glutted a small market which was dominated by New Caledonia. A large order from the United States government gave the Canadian Copper Company an outlet for its product which its competitors did not enjoy, and assisted materially in preserving that company from a similar fate.

About 10,000 tons of ore were left in the roast yard near the smelter when the works were shut down. This was subsequently sold to Joseph Wharton and Company, and smelted by Thomas Travers between July, 1897, and February, 1898, at the Murray smelter to a 25 per cent. matte. The Murray mine has been under various options. The Mond Nickel Company prospected it with a diamond drill under an option which they did not exercise. Toronto capitalists did some drilling as well, and forfeited a cash payment of $10,000 on the property. F. H. Clergue entered into an agreement to buy the property for his enterprises, which, after making a substantial payment, he did not complete. The property was eventually sold to the Dominion Nickel-Copper Company, which disposed of it in turn to the British America Corporation, Limited, and the latter now propose to make it the site of their principal operations.

[1] Nickel and Copper Deposits of the Sudbury Mining District, p. 31.

The Dominion Mineral Company

This is the third of the three pioneer companies actively working at the time the Royal Commission on Mineral Resources made its report in 1890. The period of operation corresponded closely with that of the Vivians and, like them, it was not able to overcome the trying conditions of the early 'nineties.

The company was incorporated by a special Act of the Dominion Parliament in 1889 (52 Vic., cap. 102), John Ferguson of North Bay, James Worthington of Toronto, and Louis S. Forget of Montreal, being three of the first directors. A number of prominent business men of Montreal became shareholders, and the company had excellent connection and support. It owned the Blezard and Worthington mines and carried on its mining there during the four years of its activity. The Blezard mine was opened up in the summer of 1889, and shut down finally in 1893, having produced about 100,000 tons of ore, the greater part of which was taken from open pits. Mining was started at the Worthington in the summer of 1890. In the following year a small shipment of ore was made which contained 10 per cent. of nickel and 3 per cent. of copper, and work was continued on this property until September, 1894. A smelter was built at the Blezard, and a standard matte containing from 18 to 20 per cent. of copper and 24 to 26 per cent. of nickel was produced. After the Blezard was shut down, the smelter was kept running until July, 1895, on ore from the Worthington. With the exception of a little development work in the fall of 1895 on the property known as the Cameron mine, about two miles southwest of the Blezard, no further work was done by this company. Internal differences in the management and the market conditions are given as the cause for cessation of work; Barlow ascribes it to "bad business management." The Worthington property was bought by the Mond Nickel Company, and is now being worked by them. In 1916 the same company took an option on the Blezard, on which diamond drilling is now being done.

The Drury Nickel Company, Limited

This company was incorporated under the Ontario Companies Act on January 14th, 1892. The authorized capital was $500,000, of which $150,000 was preferred. R. P. Travers of Chicago and his American associates were the principal shareholders. Thomas Travers, late Mayor of Sudbury, was mine captain, and subsequently became business manager of the company. Mining operations were confined to the Inez mine in the township of Drury, which was called locally the Chicago and also the Travers mine. A one-third interest was bought outright, and the remaining interest leased from the owner, who still retains it. The property was secured in 1890, and mining began in February, 1891. A roast yard was prepared, suitable buildings erected, and a plant installed at the mine, at which the ore was smelted to matte. The greater part of the mining was done by means of open cuts. While the ore was rich, the output was small; the overhead charges were too heavy for the returns, and the company was compelled to stop mining in 1892. Mining and smelting were resumed in 1893, and abandoned finally in a short time.

The matte was carried by a one-rail overhead tramway to Worthington station, seven miles distant, and consigned to the Emmens Metal Company, near New York, to be refined. While a considerable shipment of matte was in its possession,

the refining company got in financial difficulties. There was some trouble in recovering the matte, which could not be sold in the regular market when finally obtained, owing to the general depression of trade. It was eventually sold to Joseph Wharton and Company, who advanced funds to the company to enable it to renew its operations, taking a mortgage on its assets as security. An option was taken on some deposits in Trill township, in the hope that an enlarged ore supply and increased production would put the business on a better basis. The company was reorganized under the name of the Trill Mining and Manufacturing Company, Limited, and a new Ontario company incorporated under that name on July 11th, 1896, with a capital of $1,000,000, of which R. P. Travers held substantial control. Work was resumed in May of that year by the new company, and mining and smelting continued vigorously for a time, but both were again stopped in the following summer and never resumed. It had been demonstrated that the company could not operate profitably under the existing conditions, and the enterprise was abandoned. Mr. Wharton's mortgage was in due course foreclosed. The one-third interest in the Chicago mine he obtained in this way was eventually vested by the amalgamation with the Wharton interests in the Canadian Copper Company, which now owns it.

The Hamilton Companies

A short-lived enterprise which made its venture into the industry of 1889 under promising conditions is represented by two companies promoted by the late John Patterson, of Hamilton, and supported by a number of the leading business men of that city. Hoepfner Refining Company, Limited, was incorporated under the Ontario Companies Act on July 24th, 1899, with head office at Hamilton, and a capital of $600,000, consisting of 6,000 shares of $100 each. The proceedings on file show that stock amounting to $550,000 was issued in consideration of an agreement with Carl Hoepfner for the use of the patents covering his electrolytic process for refining nickel for a period of thirty years. The inventor had been retained a short time before by the Canadian Copper Company to experiment with his process for that company at Cleveland, but without satisfactory results. His services, together with the right to his process with improvements, were then secured by the promoters of this company, with a view to the establishment of refining works at Hamilton. A plant was built in 1900 to operate the process on Sudbury ores. Hans. A. Frasch was the resident manager, working under Hoepfner's supervision. The enterprise was hampered by unfortunate construction and arrangement of the plant, which involved expense and delay, and in the end the process could not be made a commercial success. The inventor died suddenly in Colorado, and the company attempted to operate a new process that had been worked out in the meantime by Frasch, which also proved a failure. The operations of the company extended over a period of about two years, and are said to have resulted in heavy loss. Honourable J. M. Gibson was president; John Patterson, secretary; John Moody, treasurer; J. V. Teetzel, Dr. Hoepfner, A. T. Wood and W. F. Fuerst, of New York, directors.

The Nickel Copper Company of Ontario, Limited, was a closely associated Ontario company incorporated on January 9th, 1900, with a capital of $5,000,000, of which more than half was issued. The executive and the shareholders, chiefly

prominent business men of Hamilton, were substantially the same as in the refining company. The arrangement presumably was that this company would operate the mines and furnish the supply of matte, which the refining company would refine to the finished metal. The Whistle mine was bought, and considerable testing and development done on the property by this company, which experimented with a self-roasting plant. Some ore was taken from the Whistle mine, but commercial operations were never carried on either at the mine or at the refinery. The mining properties were sold to the Dominion Nickel-Copper Company and the Whistle mine was the first Sudbury property acquired by the latter. It is now owned by British America Nickel Corporation, Limited.

Lake Superior Power Company

From 1899 to 1903 this aggressive corporation was engaged in active operations in mining and smelting nickel as one of its associated undertakings. The connection with the mining industry is interesting in the attempt to co-ordinate it with its other industries by utilizing the sulphur in the Sudbury ores in the manufacture of pulp, and the metal contents in the production of ferro-nickel. As a result of experiments on different ores in the district, the Gertrude mine was thought to be the most suitable for the special requirements of the company, and it was accordingly purchased in 1899. Development work was continued at the mine during the following year, and after railway connections were made the construction of a smelter was commenced and finished in June, 1902. With a view to extended operations, the Elsie mine near at hand was also acquired. Mining began at the Elsie in July, 1901, and in October of that year shipments were made to the roast yards at the Gertrude mine. The company made an agreement with the Vivians for purchase of the Murray mine, which was not concluded, although a substantial payment was made and forfeited. The smelting plant continued to operate for some time; but in 1903 the financial difficulties of the parent enterprise terminated all operations at the mine and the smelter. The properties were finally sold to the Booth-O'Brien interests, and by them transferred to the British America Nickel Corporation, the present owners.

The Dominion Nickel-Copper Company, Limited

This company has already been mentioned in connection with the sale of its properties to the British America Nickel Corporation, Limited, which is now making arrangements to operate them as already described. Dr. Coleman refers to this company in his statement that, "an important advance in the development of the region has been made within the last three years in the formation of a strong company for the opening up of the eastern and northern ranges," to which he adds that "with its strong financial support and ample supply of ore, the prospects for the new company seem bright."

While the company spent large sums in valuable exploration work and in the purchase of mines, it never reached the stage of commercial operation. Its principal part in the history of the industry is in the proving of ore reserves and in the accumulation of different groups of properties which have been transferred to its vendee, the British America company, already mentioned. It acquired all the

properties of the Hamilton companies, which included the Whistle mine and a number of other locations on the eastern and northern ranges. It subsequently bought the Murray mine from the Vivians, and about the same time the Gertrude and Elsie mines and all the other holdings of the Clergue interests. A large amount of money was spent in exploration work, which added to the reserves at the Murray and Whistle mine, and established the value of other properties. The management concentrated its attention on the Whistle property, and made all arrangements with a view to the erection of the proposed smelting plant at that mine. A surface plant was put up, and much development work done on the mine, from which several carloads of ore were shipped as an experiment to American steel works for making ferro-nickel. A short railway called the Nickel Range railway was built from the Canadian Northern Ontario railway near Selwood Junction to the Whistle mine, and power transmission lines were also constructed from the plant of the Wahnapitae Power Company. A site had been selected, and the plans made for the erection of a plant at the Whistle property, when in September, 1912, as already stated, an option on the Ontario assets was given, which eventually resulted in their sale. The company was incorporated under the Dominion Companies Act on August 30th, 1907, with a capital stock of $10,000,000. The principal shareholders were J. R. Booth of Ottawa, M. J. O'Brien of Renfrew, F. B. Chapin of Toronto, and a few Ottawa capitalists. J. N. Glidden was the first manager of the company, but was succeeded by J. A. Holmes.

The foregoing does not exhaust the list of all the concerns that in various ways have been connected with the industry. The Great Lakes Copper Company did substantial mining at the Mount Nickel mine in Blezard township, and put up a smelting plant to operate the process of Anton Graf for the production of high grade matte from unroasted ores. The company owned other properties and carried on diamond drill explorations. Its operations extended from October, 1899, to May, 1901, when the proposed methods having proved unsuccessful, the works were shut down.

The Algoma Nickel Company sank a number of shafts and made test pits on deposits in the township of Lorne in 1891. Other concerns, among them the Emmens Metal Company, have had no better success.

Thomas A. Edison, the famous inventor, proposed to enter the field of nickel mining in order to secure a supply of nickel for a newly invented storage battery. He spent a good deal of time and money in diamond drilling on sites located by magnetic instruments, but did not find any deposits of ore.

None of the undertakings of any company other than those at present operating has been successful, and their several failures represent the loss in the aggregate of many hundreds of thousands of dollars. Various reasons, local and personal, have been assigned in explanation of the common result. Looking back from a later date at the development of the industry, it may be questioned whether the true reasons do not lie deeper. Failure was inevitable unless a solution could be found of the problems inherent in the industry of a limited market, technical skill, command of capital, and an economical method of refining.

CHAPTER IV

Nickel Deposits of the World

INTRODUCTION

While nickel is widely distributed in nature, occurring as an essential or as an accessory constituent of numerous minerals, and having been found even in the ashes of certain marine plants, known workable deposits of the metal are confined to fewer localities than are those of the more common metals. The deposits of two countries, the Province of Ontario and the French island colony of New Caledonia, as has been shown on preceding pages, control the market for the metal.

Nickel is found native, alloyed with iron, in meteorites and in a few terrestrial minerals, but this form of the element, while of scientific interest, is of no economic importance. It has been detected in numerous igneous rocks, especially magnesian varieties, where it probably occurs most frequently as a constituent of the silicate, olivine. According to F. W. Clarke, in 262 analyses of igneous rocks made in the laboratory of the United States Geological Survey an average of 0.0274 per cent. of nickel oxide was found. Had it been sought for in all cases, this figure might have been slightly reduced, but perhaps not materially.[1]

As a constituent of the solid crust of the earth nickel occurs in greater quantity than copper, a fact that would scarcely be credited from a consideration of the much wider distribution of workable deposits of the latter and the production of the two metals. In a discussion of the relative abundance of the elements, Clarke shows that the igneous rocks contain iron and nickel in the porportions, approximately, of 4.56 of the former to 0.020 of the latter;[2] the proportion of copper is probably about 0.010, while the proportions of two other common metals, zinc and lead, are still less. It can thus be said that nickel is less amenable to concentration by the agencies that tend to produce workable deposits than are the other metals mentioned.

A small percentage of nickel usually, if not always, occurs in certain iron ores, especially in the titaniferous variety and in those of a residual nature derived from the weathering of basic igneous rocks. Ores of the former class that occur in Ontario universally contain small percentages of the metal, varying from 0.08 to 0.80.[3] Nickeliferous iron ores of residual origin will be described on later pages.

Basic igneous rocks in various parts of the world contain nickel in quantities sufficient to show that, while it occurs in few countries in deposits that are of economic importance, still the metal is often present in one-tenth or more of the

[1] The Data of Geochemistry, p. 691, 3rd Edition, Bull. 616, U.S.G.S. [2] *Ibid*, p. 27.

[3] W. G. Miller, Rept. British Ass. Ad. Sci., 1897, p. 660, and Ont. Bureau Mines, Vol. VII, p. 230, and F. J. Pope, A.I.M.E., Vol. XXIX, 1899, pp. 397 *et al.*

quantity that is of commercial value. For instance, a trap dike that outcrops at the edge of the Rideau canal in southeastern Ontario, was found to contain as much as 0.612 per cent. of nickel.[1]

Few analysts have taken the trouble to determine the percentage of nickel in rocks. In analyses available of Canadian rocks the presence or absence of nickel is rarely mentioned. It will be seen that this statement applies even to most of the analyses of the Sudbury norite that are quoted from various authors in this volume. Analyses of Canadian rocks have not been collected and published in readily available form, as have those of the United States, but the content of NiO in a few may be given. "The serpentines of the altered Silurian rocks in Eastern Canada [Quebec] often form vast masses, almost without admixture. . . . The almost constant presence of small portions of oxides of chrome and nickel is to be remarked in the analyses, not only of these serpentines but of the other magnesian rocks of the region."[2] In two specimens of serpentine from Orford, Que., the percentages of NiO are given as 0.26 and 0.15 respectively.

A peridotite (dunose) from the junction of Eagle creek and Tulameen river, British Columbia, was found to contain 0.10 per cent. of NiO.[3]

Doubtless if it is looked for, NiO will be found in similar percentages in numerous other Canadian rocks. Analyses showing a lower percentage are available from a number of localities.

In the chemical laboratory of the United States Geological Survey many detailed analyses of rocks have been made. The following list giving the percentage of NiO in rocks from widely separated localities serves to illustrate the statement that nickel is widely distributed.[4] In the analyses selected the percentage of NiO is in all cases 0.05 or more. Numerous analyses showing a lower percentage might be given. Similar nickeliferous rocks are found in various parts of the world, but in many analyses the percentages of the metal have not been determined.

Nickeliferous Rocks

(A) Massachusetts, serpentine from seven localities, 0.17, 0.21, 0.45, 0.53, 0.40, 0.47, 0.33. (B) Connecticut, hornblende norite 0.9. (C) New York, peridotite 0.9. (D) Pennsylvania, pyroxenite 0.5. (E) North Carolina, pyroxenite 0.11. (F) Kentucky, peridotite 0.10. (G) Missouri, granite 0.20, porphyry 0.15. (H) Texas, nepheline basalt 0.06. (I) Michigan, peridotite 0.21, diabase 0.10. (J) Minnesota, hypersthene gabbro 0.06, olivine gabbro 0.16. (K) Yellowstone National Park, Electric Peak, pyroxene-mica diorite 0.09, quartz-pyroxene-mica diorite 0.05, augite-andesite porphyry 0.06, Absaroka range, monzonite 0.10, quartz diorite porphyry 0.19, quartz-mica diorite porphyry 0.17, banakite dike 0.14. (L) Montana, hornblende picrite 0.09, pyroxenite 0.11, peridotite 0.16, shonkinite 0.07. (M) Idaho, diorite 0.12. (N) Colorado, perofskite-magnetite rock 0.05. (O) Arizona, mica basalt 0.08. (P) Nevada, andesitic perlite 0.07. (Q) California, quartz diorite 0.05, altered peridotite 0.09, diorite 0.05, pseudo-diabase (ornose) 0.10, andesite 0.20, basalt 0.41, black serpentine 0.33, pyroxenite 0.07, gabbro 0.06, serpentine (pyroxenite) 0.11. (R) Oregon, peridotite (saxonite), the matrix of the silicate nickel ores, 0.10, olivine separated from the same 0.26, hypersthene-augite andesite 0.05, serpentine 0.13. (S) Hawaiian Islands, picritic basalt 0.09, plagioclase basalt 0.05, porphyritic gabbro 0.12, olivine basalt 0.08, olivine separated from latter 0.34.

[1] Ont. Bureau Mines, Vol. VII, p 231.

[2] Geology of Canada, 1863, p. 472.

[3] Geol. Sur. Can., Memoir 26, p. 53, and U.S.G.S. Bull. 591, p. 210.

[4] Bull. 591, U.S.G.S

Nickel Minerals

Among the numerous compounds, in which nickel occurs in nature, the following, from the economic point of view, may be said to be the most important:—

Pentlandite..........(Fe, Ni) S.	Gersdorffite..........Ni As S
Millerite.............Ni S	Breithauptite........Ni Sb
Niccolite.............Ni As.	Annabergite.........$Ni_3 As_2O_8+8 H_2O$
Chloanthite..........$Ni As_2$	Garnierite.

Pentlandite, which contains varying percentages of nickel and iron, is believed to be the source of nearly all the nickel produced from the pyrrhotite-chalcopyrite ores of the Sudbury area. In the ores of certain mines, such as the Worthington, the mineral can be readily distinguished in hand specimens. Usually, however, it is identified only on polished or etched surfaces. Details concerning the

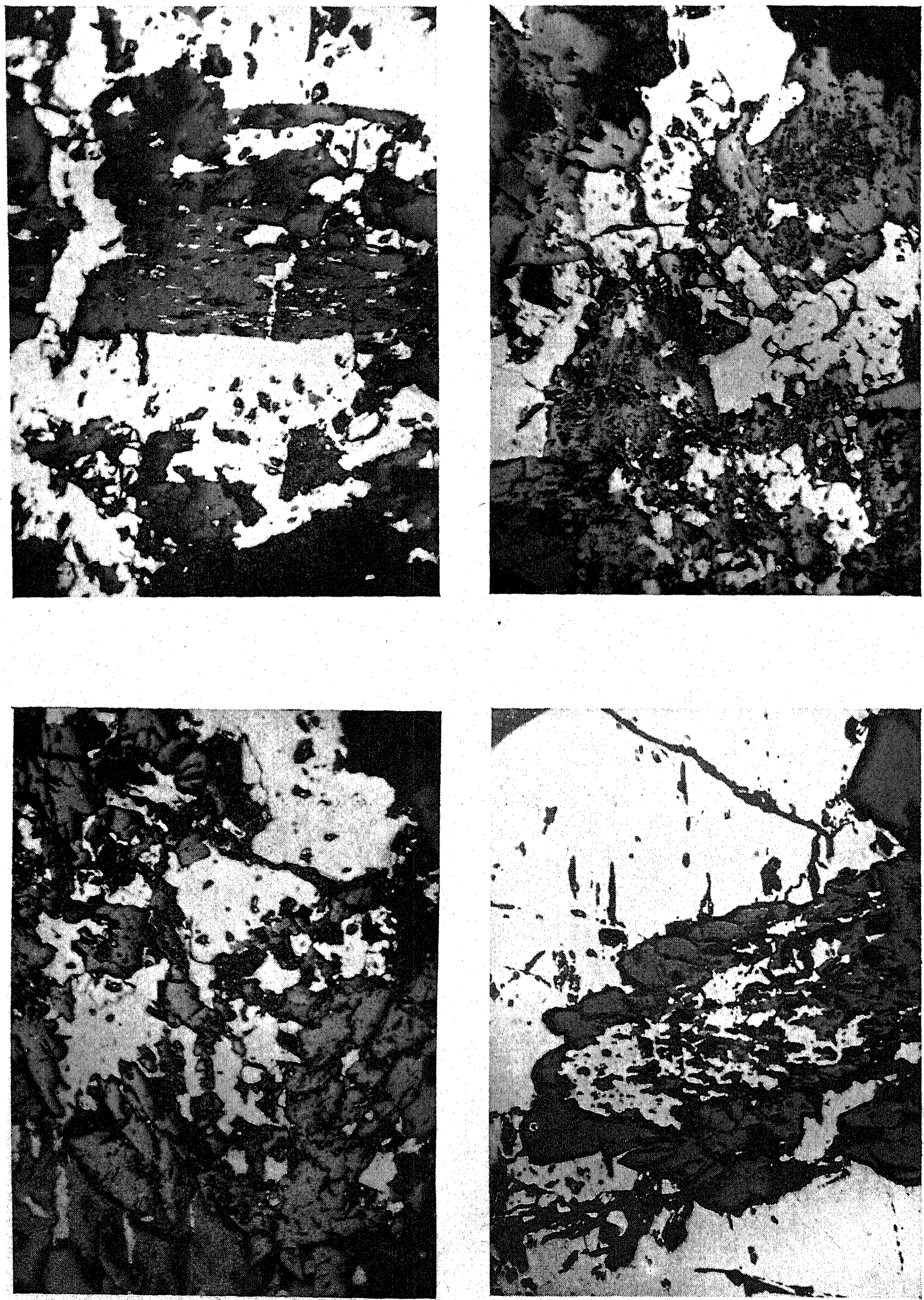
Polished and etched surface of ore, showing pentlandite in veins cutting pyrrhotite; magnified 50 diameters; Copper Cliff mine, Sudbury area, Ontario.

Photomicrograph by Wm. Campbell.

occurrences of the mineral with the ores of Sudbury are given in the reports of Barlow, Coleman and other writers and need not be repeated here. Illustrations of the modes of occurrence of the mineral will be found in following pages.

Gersdorffite and millerite have been observed only occasionally in the Sudbury ores. It may be added that polydymite, Ni_4S_5 or Ni_3FeS_5, occurs at the Vermilion mine and doubtless in other Sudbury deposits.

Niccolite, chloanthite, breithauptite and annabergite are of common occurrence in the veins of the Cobalt area. The first mentioned mineral has been found in small quantities in two or three of the Sudbury deposits.



Polished surfaces of sulphides and norite, Creighton mine, Sudbury area, Ontario. The white areas are the sulphides—pyrrhotite, chalcopyrite and pentlandite; the dark areas are norite. Magnified 70 diameters.

Photomicrographs by Wm. Campbell.

Linnæite, a sulphide of cobalt, $Co_3 S_4$, in which the cobalt is replaced by nickel, and to some extent by iron and copper in varying proportions, occurs at Mine La Motte, Missouri, which has been a small producer of nickel and cobalt.

Garnierite is second only to pentlandite as a source of nickel. It is essentially a hydrated silicate of nickel and magnesium, but is of somewhat indefinite chemical composition. Dana says its formula is "perhaps H_2 (Ni,Mg) Si O_4 + aq, but very variable in composition, particularly as regards the mutual replacement of nickel and magnesium, and not always a homogeneous mineral. Liversidge has attempted to distinguish two varieties, one of which is dark green and unctuous, *noumeite;* the other rarer, pale green and adhesive to the tongue, *garnierite.*"[1] There are other hydrous nickel-magnesium silicates, more or less related to garnierite, such as genthite, pimelite and schuchardite. Garnierite is an alteration product of serpentine, derived from peridotite, and is the essential source of the nickel in the ores of New Caledonia and elsewhere, although other compounds of the metal, the products of weathering, occur in association with it.

Classes of Ores

The ores that are worked primarily as sources of nickel fall naturally into three classes—(a) Sulphides, represented especially by the pyrrhotite-chalcopyrite ores of Sudbury and Norway. Ores of this class have been mined to a much smaller extent in Pennsylvania, Tasmania, Sweden, Italy, South Africa and elsewhere. The sulphides of iron and copper that are associated with the lead ores of southeast Missouri should also be mentioned as they have been worked for cobalt and nickel. (b) Silicates or oxidized ores, of which the chief occurrences are those of New Caledonia. Similar ores occur in Greece, Madagascar, North Carolina, Oregon and in other countries. (c) Arsenical ores, usually containing both nickel and cobalt, the principal working mines being those of Cobalt, Ont. Ores of this nature have been worked in Saxony, Bohemia, France and elsewhere.

Other sources of nickel are (d) blister copper, which contains nickel and other metals, (e) manganese ores of the earthy class known as wad, sometimes rich in cobalt and to a lesser extent in nickel, (f) nickeliferous iron ores, such as those of Cuba, the nickel forming a valuable ingredient in the iron or steel produced from such ores, but not being separable, commercially, from the iron.

By-Products of Nickel Ores

Nickel in commercial quantities in pyrrhotite-chalcopyrite ores may be said to be an accessory constituent, since many deposits of this class do not contain the metal in workable quantities. In addition to nickel and copper these ores that are worked contain gold, silver, platinum, palladium and other metals as by-products. These are discussed in the section devoted to precious metals. At Sudbury, as is shown on other pages, no use has yet been made of the sulphur or the iron in the ores. The platinum in the Sudbury ores is known to occur essentially as the arsenide, sperrylite, but the form in which palladium occurs has not been determined. Discovery of compounds of the latter metal would be of great interest, both from the scientific and the economic point of view.

[1] Descriptive Mineralogy, 6th Ed., p. 677.

The silicate ores of nickel have been treated essentially for the one metal, although attempts have been made to utilize the iron by smelting to a nickeliferous pig. Excepting these two metals the silicate ores contain no constituents of value.

The cobalt-nickel ores of Cobalt contain several constituents in commercial quantities. The chief of these is silver. Then there are cobalt, nickel and arsenic. Certain of these ores also contain an important quantity of mercury.

Historical Notes on Nickel Mining

The history of nickel mining may be conveniently divided into two periods, namely, that preceding the working of the New Caledonia deposits and that which has followed. During the last 30 or 40 years the production has increased enormously and New Caledonia and Sudbury have dominated the market.

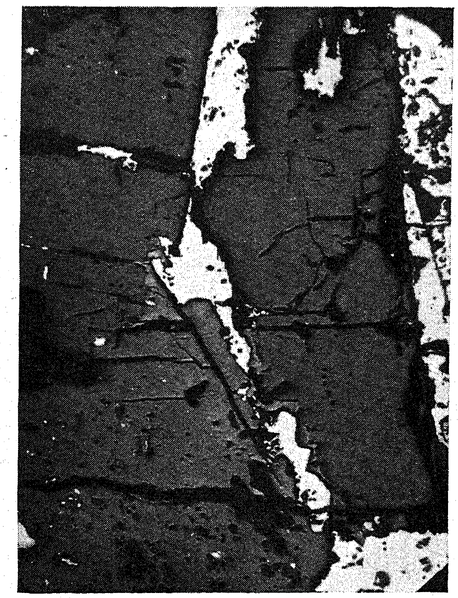
Although the metal nickel was discovered by Cronstedt in 1751, in niccolite from a cobalt mine in Sweden, an alloy, containing copper, zinc and nickel, had been in use in China for thousands of years. Coins, found in Persia, dating from prior to 200 B.C., contain percentages of copper and nickel similar to those in coins made at the present time. It is interesting to note that use was also made, in early ages, of the closely related metal cobalt, glass coloured with this metal having been found in the ruins of Troy and in the graves of the ancient Egyptians.

Owing to the hardness of nickel and the temperature required to melt it, there is little likelihood that any use was made of the metal except in alloys until modern times. In considering the use by the ancients of nickel alloys, it may be pointed out that tin had a similar history. Bronze, an alloy of copper and tin, was used for ages before the latter metal was employed in the unalloyed state.

It was some time after Cronstedt's discovery that pure nickel was prepared, Bergman extracting it in 1775. The first refining of the metal for commercial purposes appears to have been done at Schneeberg, which had long been the site of the cobalt industry. For some years the ores of nickel treated were those that occur in the cobalt deposits, especially of Saxony and Bohemia. In 1838 it was found that the pyrrhotite ores of Sweden contained nickel, and a refining plant was erected. Nickel ores were also discovered in Norway and several plants were erected in that country which became the largest producer of the metal. Norway continued her lead until 1877, when she was eclipsed by New Caledonia, export of ores from this country beginning in 1875. Immediately prior to the advent of New Caledonia as a producer, the world's output of nickel appears to have been about 500 metric tons a year. Norway's greatest annual output is said to have been 360 tons in 1876.

In the period preceding the beginning of mining in New Caledonia several countries, in addition to Scandinavia, Germany and Austria, were producers of nickel ore. Mines in Piedmont, Italy, were operated between 1860 and 1870, the ore produced being similar to the Norwegian, but the deposits were of smaller size. The United States had one important mine, that at Lancaster Gap, Penn. Although its total production is given as only about 2,000 tons, its annual output at one time represented about one-sixth that of the world. This mine is said to

Blezard Mine.



Blezard Mine.

Blezard Mine.

Creighton Mine.

The three specimens from the Blezard mine, Sudbury area, Ontario, are polished sulphides (white), and norite (dark). Magnified 70 diameters. The polished specimen from the Creighton mine shows a veinlet of pentlandite, with good cleavage, in pyrrhotite (white). Magnified 70 diameters.

Photomicrographs by Wm. Campbell.

have been worked for copper prior to 1774, and subsequently at various periods without much success. It was not until 1853 that the ore was found to contain nickel. Ten years later the mine became a nickel producer. Owing to competition from New Caledonia and Sudbury, the mine was finally closed in 1891. It may be added that the ores from Lancaster Gap contain pyrrhotite and chalcopyrite and in this respect resemble those of Sudbury, Scandinavia and Italy. In this earlier period of nickel production the copper and iron sulphides that occur in certain of the lead deposits of southeast Missouri received some attention. Small shipments were made to England with the object of extracting the nickel which the ores contain.

Reference should also be made to the fact that nickel was produced from Canadian ores before the discovery of the Sudbury deposits. These ores came from the Silver Islet mine, Lake Superior, discovered in 1868, and contained nickel and cobalt, in addition to being very rich in silver. Prior to 1873 and later nickel was extracted from the matte produced from these ores at the Wyandotte, Mich., smelting works.

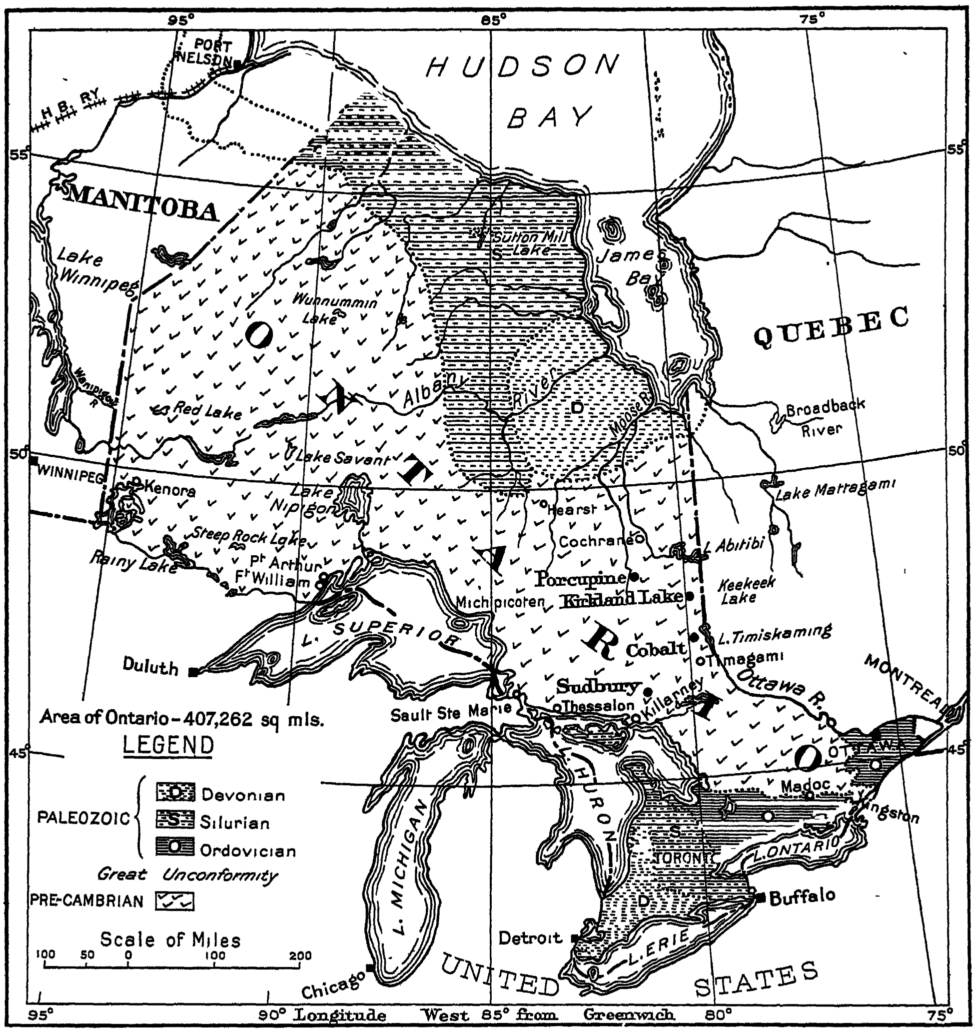
Nickel ores were refined at an early date in England. Johnson of Hatton Garden introduced nickel refining about 1830. The plant of Henry Wiggin & Co., Ltd., near Birmingham, was established, under the name of Evans & Askin, in 1832, for the treatment of cobalt-nickel ores.[1] A process for the separation of nickel from cobalt on a commercial scale was developed at this plant about the year 1836. These were the first works to refine nickel, by a wet process, in England. Arsenical nickel ores were treated almost exclusively until mining began in New Caledonia in 1875. The arsenical ores came partly from Hungary and partly from South America and elsewhere. After the New Caledonia ores came on the market another company erected a plant to treat them at Erdington, near Birmingham. Both plants are still in operation, as is also the Vivian plant, now known as the Anglo-French, in Swansea. This Vivian plant was also a pioneer in the treatment of cobalt and nickel ores.

Since the coming of the New Caledonia ores on the market, 1875, and later those of Sudbury, 1886, other sources of supply have played only an insignificant part. The difference between the price of refined nickel and the cost of production has enabled the Norwegian mines to operate, and small quantities of ore from other countries, valuable for its nickel content, have been sold from time to time. Moreover, there will always be a small production of nickel as a by-product in the refining of copper, cobalt and other ores.

Nickel Deposits of Various Countries

The geology, ore deposits and mining methods of Sudbury are described on pages 103 to 227, and Alexo mine, 228 to 232. Then follow descriptions of the nickel resources of New Caledonia, pages 234 to 263, Norway, 264 to 265, and other countries in alphabetical order, 266 to 286.

[1] Birmingham Handbook, Brit. Ass. Ad. Science, 1913.



Geological Map of Province of Ontario, Canada, showing location of the Sudbury Area.

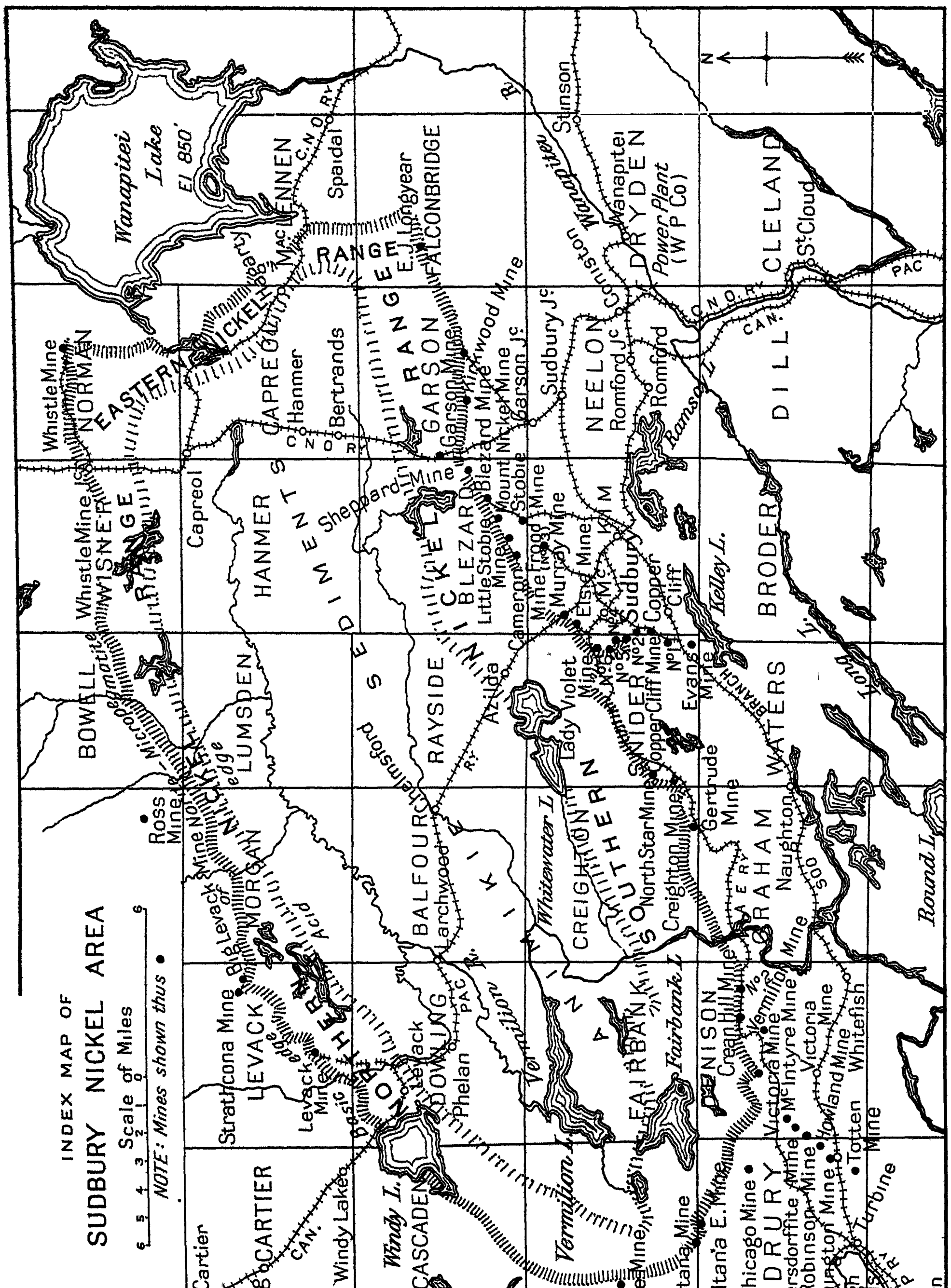


Fig. 1. Map of the Sudbury Nickel-Copper area, Ontario, Canada, showing the location of the mines. The outlines of the norite-micropegmatite are also indicated.

GEOLOGY OF SUDBURY AREA*

The surface geology of the Sudbury nickel-copper area has been described in considerable detail by various authors. The present report deals especially with the size, structure and character of the ore bodies and their relations to adjacent rocks.

While this report will be confined mainly to a study of the ore bodies, it may be helpful to give a brief outline of the geological history of the area. The reader who desires to obtain more details regarding the general geology may do so by consulting the reports referred to in the bibliography on following pages of this Report.

The rocks have been divided into the groups indicated in the following table, the oldest formations being shown at the bottom of the column. This classification differs somewhat from those employed by other authors.

TABLE SHOWING THE ROCK GROUPS IN THE SUDBURY NICKEL-COPPER AREA

PRE-CAMBRIAN

Keweenawan Series [1]	Olivine Diabase Dikes Trap Dikes Granites Norite-micropegmatite Gabbros
	Intrusive Contact.
Animikie Series	Chelmsford Sandstone Onwatin Slate Onaping Tuff Trout Lake Conglomerate, Ramsay Lake Conglomerate
	Unconformity
	Greenstones, including Sudburite [2]
	Intrusive Contact.
Timiskaming Series [3]	Wanapitei Quartzite McKim Greywacké Copper Cliff Arkose
	Unconformity [4]
Grenville Series	Crystalline Limestone, Quartzite, Various Schists and Gneisses

* Mr. Cyril W. Knight, Assistant Provincial Geologist of Ontario, who has spent some months, during each of the years 1915 and 1916, in a study of the Sudbury nickel-copper deposits, has kindly furnished the Commissioners with the following descriptions of the geology and of the ore bodies, together with his views on the origin of the latter.

[1] Some of the intrusives here grouped with the Keweenawan are possibly of later age.

[2] These rocks have not been observed in contact with the Animikie series, but they are believed by some observers to be older than the Animikie. They may be Keweenawan in age.

[3] In this area these rocks are given the name of Sudbury series by some authors.

[4] The unconformity has not been seen in the Sudbury area, but is known elsewhere in Ontario.

Grenville Series

The oldest rocks in the area are named the Grenville series. They consisted originally of sediments which have now been changed to various schists and gneisses. In addition to the schists and gneisses there are also quartzites and, very rarely, crystalline limestone. The Grenville series has not yet been found in actual contact with the Timiskaming series, but it is thought to be older than this series because it is more highly altered, or metamorphosed. The formations on which the Grenville series rested originally are unknown. In southeastern Ontario, however, about 200 miles to the southeast, the series rests on pillow lavas and green schists called the Keewatin series[1]. Certain green schists associated with iron formation, in the township of Hutton, a few miles north of the Sudbury area, may be of Keewatin age. In the Sudbury area Coleman has mapped an extent of the Grenville rocks to the south of the Mond Nickel Company's smelter at Coniston, about eight miles from the mines.[2] It may be added that Robert Bell originally described the Grenville rocks in the Sudbury area.[3]

Timiskaming Series

The next youngest group of rocks is the Timiskaming series, the Sudbury series of certain authors. It consists of quartzites, greywackés, arkoses, slates and conglomerates. The series is supposed to have a total thickness of 29,000 feet[4]. The rocks were no doubt laid down under the ocean in horizontal beds. They have since been subjected to mountain-building forces which have often tilted the beds into steeply inclined positions, Fig. 2, the greywackés and slates sometimes being changed to schists and gneisses. The Timiskaming series, between Worthington mine and Victoria mine station on the Canadian Pacific railway, contains coarse boulder conglomerates. There are boulders of granite and granite gneiss two or three feet in diameter. The presence of the granite fragments shows that there was a granite formation older than the conglomerate. This old granite floor has not been discovered in the Sudbury area, although it has been found elsewhere in the Canadian shield. It may be added that every granite yet found in contact with the Timiskaming series in the Sudbury nickel-copper area is younger than these sediments.

Greenstones, Including Sudburite

Associated with the Timiskaming series there are some greenstones whose age is not definitely ascertained. They are evidently younger than the Timiskaming series, but whether they are pre-Animikie in age or Keweenawan is not certainly known. The greenstones are basic rocks, sometimes having pillow structures and amygdaloidal textures when they are called sudburite, Fig 59, or "older" norite.[5] They are often altered to schists. They occur mainly on the

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[1] Miller & Knight, Ont. Bur. Mines, Vol. 22, Part II, pp. 3, 9, 11, 34, 35, 45, 50, 88.
[2] Ont. Bur. Mines, Vol. 23, Part I, p. 204.
[3] Geol. Sur. Can., Vol. 9, 1896, pp. 9-11, I.
[4] Ont. Bur. Mines, Vol. 23, Part I, p. 214.
[5] Ibid., p. 215.

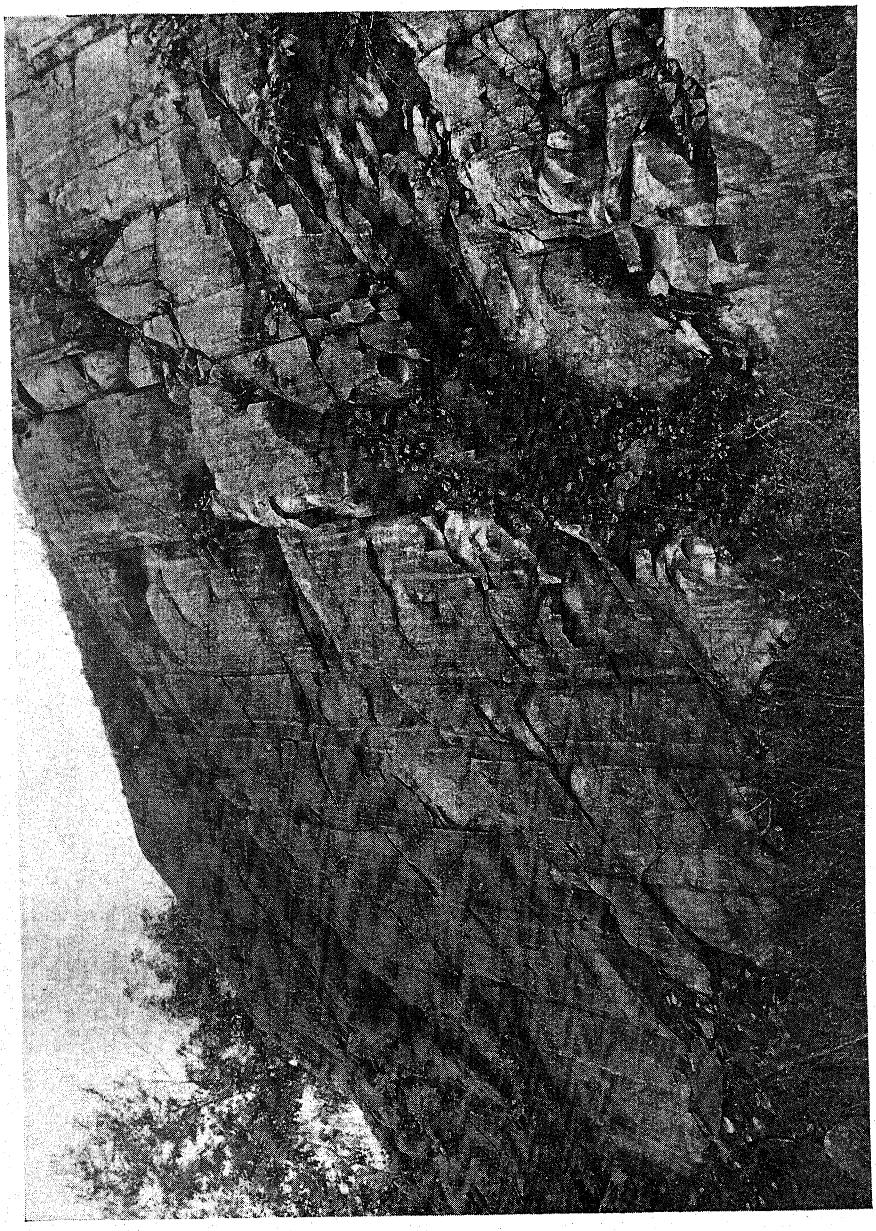

Fig. 2—Greywacké and slate, Timiskaming series, on the outskirts of the town of Sudbury. The bedding planes of the rocks have been tilted into vertical position. The cliff is about ten feet high.

southern nickel range immediately adjacent to or near the norite. Sudburite is found at the Murray and Gertrude mines, and elsewhere.

The Animikie Series

The Animikie series consists of sandstones, slates, tuffs and conglomerates, having an estimated thickness of about 9,500 feet[1]. At Ramsay lake the conglomerate rests unconformably on the Timiskaming series. The Animikie rocks are found for the most part in a remarkable depression known as the Sudbury basin. The latter is surrounded by prominent hills of the Animikie conglomerate and the acid part of the norite-micropegmatite. The conglomerate contains pebbles and boulders of quartzite, granite, and other rocks, and is regarded as an ordinary basal conglomerate.

These Animikie rocks at Sudbury are believed to be of the same age as the Cobalt series at Cobalt, Gowganda and elsewhere.

The Keweenawan Series

The Keweenawan series is the most important group of rocks from an economic point of view. During this period the nickel-copper ores were formed. In other parts of the pre-Cambrian region, notably at Cobalt and on Keweenaw point on the south shore of Lake Superior, the Keweenawan period was also a time during which valuable minerals were deposited, e.g, the silver, cobalt, nickel and arsenic ores at Cobalt, and the native copper deposits at Keweenaw point.

At Cobalt and Sudbury the Keweenawan series consists entirely of igneous rocks, but at Keweenaw point the series is made up of a stupendous pile of interbedded lavas and sediments.

In the Sudbury area there appear to be igneous rocks, of the Keweenawan series, of several ages, as shown on the table on page 105. The oldest group consists of gabbros which are medium to coarse-grained rocks resembling somewhat the norite of the area. A prominent intrusion of the gabbro stretches from the town of Sudbury southwest to Kelley lake. Gabbros are also met with at Murray, Mount Nickel and Frood mines, and elsewhere. The age of the gabbros has not been definitely ascertained. It is known that they are younger than the rocks of the Timiskaming series, since they have been intruded into this series. On the other hand, they have not been observed in contact with the Animikie rocks in the Sudbury basin, and therefore it is not possible to state definitely whether they are older or younger than the Animikie. It may be, of course, that the gabbros are not all of the same age.

The next youngest rock of this series is the norite-micropegmatite which occurs in such large volume. It is younger than the gabbro at Murray and Mount Nickel mines, at both of which places it has caught up fragments of the gabbro: The form and composition of the norite-micropegmatite are described on pages 115-121.

The granites appear to be the next youngest rocks. There is, however, some difference of opinion regarding the age of these rocks, but this matter is discussed more fully elsewhere in the report, pages 122-125. It is certain that some of the

granites are younger than the norite-micropegmatite since they are enclosed wholly by it and have evidently been erupted through it. These granites have come to be spoken of as "later," or "younger," granites.

The formation of the nickel-copper ore bodies probably closely followed the intrusion and consolidation of the granites.

After the formation of the ore bodies there followed intrusions of fine-grained trap dikes, now having the composition of uralitic diabase. These traps are met with at Creighton, Crean Hill and Worthington mines. Their age relationships were determined by C. H. Hitchcock.

The last important event in the geological history of the area was ushered in by the formation of great cracks or fissures and by the eruption into them of olivine diabase dikes. Certain of these dikes are several miles long and two or three hundred feet wide, and they intersect every rock in the area, including the Animikie sandstone in the Sudbury basin and the nickel-copper ore bodies. They are widespread throughout pre-Cambrian areas not only at Sudbury but at Cobalt, Gowganda, Porcupine and elsewhere.

While the eruption of the olivine diabase dikes constituted the last important event in pre-Cambrian times, of which there is record in the Sudbury area, it may be added that these dikes are cut by small veinlets of granitic material[1].

Granite and Granite-Gneiss

In addition to the rocks briefly described in preceding pages there is a great belt of granite and granite-gneiss immediately north of the norite-micropegmatite, on the northern nickel range. This granite and granite-gneiss are older, in so far as known, than the norite-micropegmatite, but their age relations to the Timiskaming and Animikie rocks have not been ascertained. Another belt of granite and granite-gneiss is found from 6 to 10 miles southeast of the southern nickel range; these granites are intrusive into the Tismiskaming series.

Topography, Sudbury Area*

A word may be said regarding the character of the topography. The country has an average elevation of about 1,000 feet above sea level, the highest hills not being much more than 1,400 feet above the sea. The main line of the Canadian Pacific railway crosses the area, so that a cross-section, Fig. 3, along the railway track gives a fair idea of the topography. It will be understood, of course, that there are some hills which rise 200 or 300 feet above the railway track. It is hardly necessary to point out that the well-known, characteristic feature of the area consists of a distinct, oval-shaped basin, often as level as a plain, while, in striking contrast, hills as high as 600 feet encircle the basin. The latter, where crossed by the Canadian Pacific railway, has an average elevation of 900 feet above the sea. The nature of the rocks which underlie the basin partly accounts for its shape, since the central part consists of soft sedimentary formations, while the encircling hills consist of

[1] Ont. Bur. Mines, Vol. 14, Part III, p 125.

* The entire surface of the rocks in the Province of Ontario has been glaciated during the Glacial period. Much of the surface, including that at Sudbury, is covered with super-

harder, igneous or sedimentary rocks. Beyond the basin the country consists of rugged hills, 100 or 200 feet high. The drift-covered valleys between these hills sometimes have farm lands of tolerable fertility.

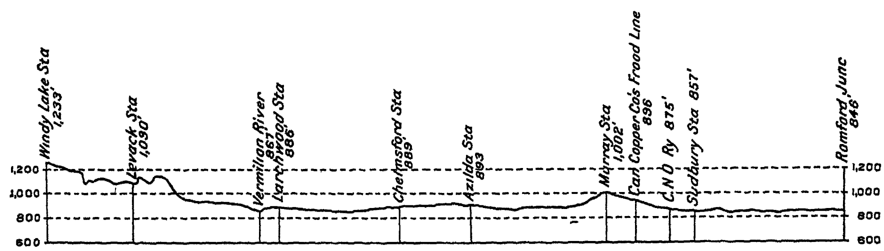

Fig. 3—Section from Romford Junction, near Sudbury, Ontario, to Windy lake, along the main line of the Canadian Pacific Railway. This section crosses the Sudbury basin and shows the elevations above sea level along the railway track. Horizontal scale 8 miles equals 1 inch; vertical scale 1,600 feet equals 1 inch.

Crush-Conglomerates and Crush-Breccias

Crush-conglomerates and crush-breccias, Figs. 4 and 5, are rocks which have been formed by disturbances resulting in crushing and brecciation. The rocks may occur in all the formations of the Sudbury area, they having been met with in quartzites, greywackés, slates, greenstones, granites, norite, and other rocks. The fragments composing the rocks are generally rounded, this variety being known as crush-conglomerate. When, on the other hand, the fragments are angular, the rock is known as a crush-breccia. The matrix which cements the fragments together consists of the more finely crushed material of the rock which has been disturbed. Sometimes the fragments in the crush-conglomerates and crush-breccias are 10 or 15 feet or more in diameter. An example of the rock in greywacké or quartzite may be seen on the hill immediately to the south of the Canadian Pacific railway station at Sudbury, Fig. 5. Here the crushed zone evidently formed a pathway for the circulation of sulphide-bearing waters, for the rock is "spotted" with blebs of sulphides.

The crush-conglomerates and crush-breccias referred to in the preceding paragraph differ only in one respect from the crush-conglomerates and crush-breccias which constitute the commercial ore bodies. In the case of the ore bodies it is the sulphides which largely form the cementing material for the rock fragments, Figs. 6, 14, while in the case of the non-mineralized crush-conglomerates and breccias it is the finely ground-up rock which forms the matrix.

Commercial Ore Bodies Made up of Crush-Conglomerates and Crush-Breccias

As already said crush-conglomerates and crush-breccias may occur in any of the rocks, but they are most commonly found along the rocks adjacent to the norite and along the so-called offsets. They furnished convenient zones

for the circulation of hot mineral-bearing waters, and consequently where they occur near the edge of the norite or in offsets they have been heavily mineralized with sulphides, thus forming the commercial ore bodies. The fragments and blocks are cemented together by the sulphides. The sulphides also impregnate or replace the rock fragments, occurring in veinlets, in irregularly shaped masses, and in disseminated grains—"spots" or "blebs."

Fig. 4—Crush-conglomerate and crush-breccia, Copper Cliff, Sudbury area, Ontario. Width of face is 2 feet 6 inches. The rock has been formed by crushing and brecciation; the more finely crushed material constitutes the matrix for the larger fragments. The commercial ore bodies consist largely of these crushed rocks, but in the case of the ore bodies the matrix consists mainly of sulphides instead of the more finely crushed rock fragments, the more finely crushed rock having been partly or wholly replaced by ore.

The "conglomerate"—like character of the nickel-copper ores was noted by one of the earliest observers, Robert Bell, who described the ore more than a quarter of a century ago in the following words[1]:

[1] Geol. Sur. Can., 1890-91, Vol. V, Part F, p. 48.

In each case the ore-mass consists of a brecciated or agglomerated mixture of the pyrrhotite and chalcopyrite along with the country rock. The included fragments of the latter are both rounded and angular, and vary in size from that of pebbles to large boulders, but the average is a few inches in diameter. Immense blocks or 'horses' also occur in the midst of the ore.

The geologists who worked in the field after Bell have also noted the "conglomerate"-like nature of the ore, but little emphasis has been laid on it, except by C. W. Dickson.[1]

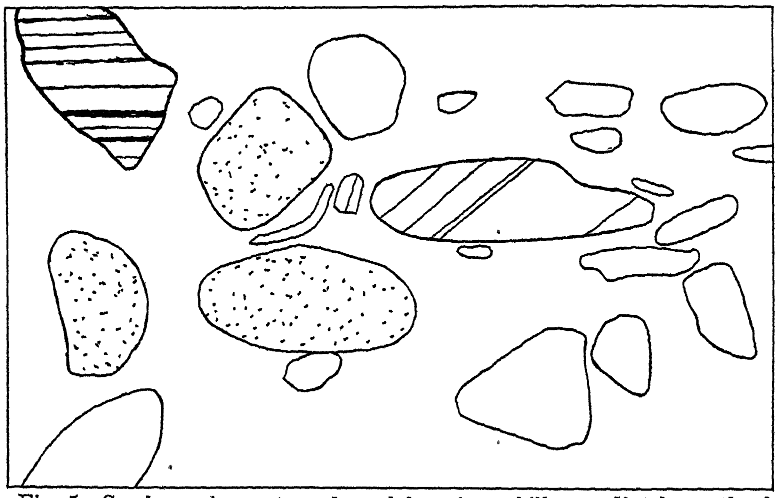

Fig. 5—Crush-conglomerate and crush-breccia on hill immediately south of Canadian Pacific Railway station, Sudbury, Ontario. The rock was formed by crushing and brecciation, and may occur in any rock such as quartzite, slate, greenstone, norite, etc. The length of the rock surface represented in the drawing is 12 feet.

Occurrences of the Ore Bodies*

1. Marginal Ore Bodies

The ore deposits occur for the most part along the outer, basic, contact of the norite-micropegmatite, but the commercial ore bodies are rarely found in the norite. On the contrary, they occur largely in the rocks adjacent to the norite, there being a comparatively small quantity of commercial ore met with in this rock. Examples of ore bodies which occur wholly or mainly in the rocks adjacent to the basic edge of the norite are the Crean Hill, Creighton, Levack, and Whistle. The Creighton is found about at the contact, Fig. 21, while the Levack ore body is wholly in the underlying granite gneiss at an average distance of about 175 feet from the contact of the norite measured at right angles to the dip of the contact, Fig. 40. While it is true that little commercial ore occurs in the norite, there is at times light, non-commercial mineralization in this rock, impregnating or replacing large masses, the sulphides often being found in the form of blebs about the size of peas, giving rise

[1] Trans. Am. Inst. Min. Eng., Vol. 34, pp. 1-67. The brecciated or conglomerate-like nature of the ore bodies is again and again referred to by Dickson; see pages 37, 43, 45, 46, 47, 48, 49, 50, 51, 54, 55, 59 of Dickson's report.

* The mine workings of the nickel-copper deposits at Sudbury have proved that the ore bodies, as they are found to-day, have neither been enriched nor impoverished by the action of surface waters. There has been formed on the surface of the ore bodies, however, a little gossan, caused by the weathering and decomposition of the ore, where the deposits are not protected by a covering of clay, gravel or other materials. Before glaciation took place, the upper part of the deposits no doubt contained a comparatively thick zone of weathering and impoverishment due to the action of surface waters. But the glaciers have long since scoured away this zone.

to what has been called "spotted" norite. The notable example of this non-commercial variety of mineralization is met with at the Creighton, where a zone three-quarters of a mile long and about 600 yards wide is thus mineralized. It may be repeated, however, that the commercial ore bodies are found almost wholly in the rocks adjacent to the norite—not in the norite.

The deposits described in the preceding paragraph are known as "marginal" deposits.

2. Offset Ore Bodies

The second class of deposits has been called "offset" deposits. The offsets are mineralized dikes. There are four main occurrences of the offsets, namely, Worthington, Copper Cliff, Frood and Foy. In the case of the first three it may be pointed out that they cannot be traced directly into the norite or so-called nickel eruptive, although they are believed by many to be of the same age as this eruptive. This relationship has not been proved nor disproved. The offsets have a maximum length of six miles and a width of from a few feet to 700 or 800 feet.

The marginal and offset deposits occur along extensive and well-defined lines that have either a northwest-southeast or northeast-southwest direction. These directions constitute lines of crushing, brecciation and shearing. It has so happened, in the case of the marginal deposits, that the lines of disturbance occur along the contact of the basic edge of the norite-micropegmatite and adjacent rocks, largely in the latter, thus accounting for the occurrences of the ore bodies in this position. The disturbances referred to have broken the rocks along their path into crush-conglomerates and crush-breccias. The ore occupies or fills the spaces between the rock fragments composing these disturbed zones. The ore also impregnates or replaces the rocks in the form of irregular veinlets, masses, and in disseminated grains.

The origin of the ores will probably remain a controversial subject for many years. All that can be said with certainty is that the sulphides were introduced after the norite-micropegmatite had solidified. This is proved beyond doubt, even if there were no other evidence, by the presence in the ore bodies, which occur exactly at the contact of the norite, of both round and angular fragments of the norite cemented together by pure sulphides.

It appears, indeed, to be a common experience to find that ore deposition is later than the igneous rock with which an ore body may be associated. The remarks of J. E. Spurr are of interest in this respect: "Where ore bodies occur in, near, or following the contact of igneous rocks," writes Spurr, "there is evidence in every case that I have seen (with the exception of certain pegmatite veins and pegmatitic quartz veins), that ore-deposition was distinctly subsequent to rock consolidation; and hence that the ore was derived from some deeper horizon."[1]

The origin of the Sudbury ores is more fully discussed in succeeding paragraphs.

A word may be added regarding the surface outcrops of the ore bodies. Some of the deposits outcrop in valleys, while others outcrop on hills. For instance, the Frood, Victoria, Crean Hill, and Garson occur on hills, while the Worthington, Creighton, and particularly the Levack, are examples of deposits which occupy pronounced valleys.

[1] Economic Geology, Vol. II, No. 8, December, 1907, p. 794.

The Shape of the Ore Bodies

The shape of the commercial ore bodies is for the most part rudely lenticular, the Creighton, Murray, Garson, Levack, and numerous other deposits having lenticular outlines. Other commercial ore bodies, like the Victoria and Copper Cliff, have the form of irregular cylinders or tubes. Some ore bodies are distinct veins.

Character of the Sudbury Nickel-Copper Ores

The character of the Sudbury nickel-copper ores may be described as being more or less "rocky." That is to say, the ore is always accompanied by rock, generally in the form of fragments, Figs. 6, 19. These fragments vary from microscopic specks to great blocks 5, 10, 15 feet or more in diameter, and they consist of granite, greenstone, norite, quartzite, greywacké, schist, or the individual minerals constituting these rocks. The rocky nature of the ore bodies makes it

Fig 6.—Character of ore at Creighton mine, Sudbury area, Ontario, ninth level, 15 feet from footwall. Greenstone boulders and fragments enclosed in sulphides (shaded area). Width of face 8 feet.

necessary to hand-pick from the ore from 10 to 60 per cent. of rock, and even this hand-picked product contains 14 to 35 per cent. or more of silica. The cleanest ore in the whole field is that which is mined from the Creighton deposit, but even from this ore there is hand-picked from 10 to 16 per cent. of rock. This hand-picked product still contains 18 to 21 per cent. of silica. The character of the ores from important mines is shown in the following table:

Name of Mine.	Per Cent. of Rock Hand-Picked from Ore.	Per Cent. of Silica Remaining in Hand-Picked Ore.
Crean Hill	50	28-35
Creighton	10-16	18-21
Garson	25	24*
Victoria	25	14
Levack	33	14
Worthington	60	26†

* Including Kirkwood mine. † Including Worthington No. 2.

The ore consists almost wholly of three minerals; namely, pyrrhotite, chalcopyrite and pentlandite. Several other minerals occur but these are found in com-

paratively insignificant quantities. Coleman[1] and Barlow[2] have described the minerals in great detail. Pentlandite is the nickel bearing mineral, and it contains 22 per cent. of this metal. Chalcopyrite is the copper bearing mineral, containing as it does 34.5 per cent. of copper.

The Norite-Micropegmatite, its Form and Composition, and its Relation to the Nipissing Diabase

The norite-micropegmatite has been mapped by Coleman as an oval area surrounding a basin composed of conglomerates, sandstones, tuffs and slates, Fig. 1. The average width of the intrusive on the southern nickel range is 3.1 miles and on the northern range 1.9 miles. The length of the area is about 36 miles and its width, including the sedimentary basin, 16 miles.

This great mass of igneous rock has been shown by the workings of the various mines and by diamond drilling to have sometimes a gigantic dike-like form, Fig. 7, and sometimes a sheet-like form, Fig. 8. On the southern nickel range, where most of the mines occur, more is known about the dip of the basic edge of the

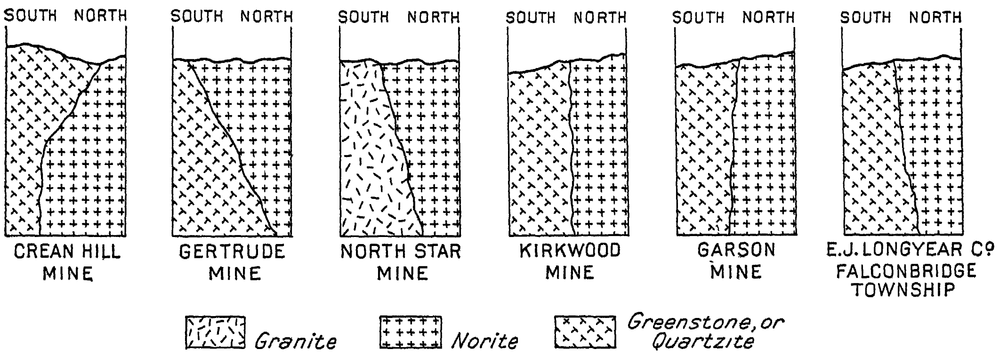

Fig. 7—Cross-sections illustrating dike-like character of the contact of the basic edge of the norite-micropegmatite (the so-called nickel eruptive) on the southern nickel range, Sudbury, Ontario. These diagrams show that the norite-micropegmatite has partly a dike-like form.

intrusive than is known elsewhere. It has been found that the basic edge of the intrusive has a dike-like contact at Crean Hill, Gertrude, North Star, Garson, on the E. J. Longyear Company's property, Falconbridge township, and on part of the eastern nickel range. At Crean Hill the intrusive in the shaft section dips at an angle of 50° to 60° to the southwest, under the greenstones, to about the sixth level, below which it is more or less vertical, Fig. 18. Generally speaking, the contact of the intrusive at Crean Hill may be said to be more or less vertical; *i.e.,* dike-like. The intrusive at the Gertrude dips at 55° to 67° to the north. At the North Star mine the dip of the intrusive is 75° to 80° to the northwest—also a dike-like occurrence. The dip of the intrusive at the "northwest" ore body of Garson mine is 80° to 90° to the southwest. The main ore body at the Garson dips at angles of 53 to 60 degrees to the southeast; if the ore body here follows the dip of the intrusive, then the latter is plunging to the southeast below the adjacent rocks for at least 1,800 feet, not to the northwest, as it should do if it had a sill-like form. Three miles east of the Garson, on the E. J. Longyear Company's property, the

[1] The Nickel Industry, 1913, Dept. of Mines, Canada.
[2] Geol. Sur. Can., Report on the Nickel and Copper Deposits of Sudbury, 1907.

dip of the intrusive is from 70° to 90° to the north, in one instance 85° to the south. On the eastern nickel range there is little definitely known about the contact of the intrusive, but I am informed by C. H. Hitchcock that there are places, proved by diamond drilling, at which the intrusive dips towards the east—under the greenstones. In addition to the above localities, where it has been proved that the intrusive has a dike-like contact with adjacent rocks, the Victoria ore body may be mentioned. The ore body has a vertical dip, with a pitch of 70° to the southeast. If the intrusive has the same dip as the ore body, then here also it has a dike-like form. The Kirkwood ore body, a mile and a half west of the Garson mine, has also a vertical dip; if the intrusive has a similar dip it will likewise have a dike-like contact.

Some of the various dips of the outer edge of the intrusive on the southern nickel range referred to in the preceding paragraph, are illustrated in Fig. 7, which shows the dike-like nature of the norite-micropegmatite.

The sill-like nature of the norite-micropegmatite, on the southern range, has been proved at the following localities: Lot 2 in the fifth concession of Denison township, Creighton mine, Elsie mine, Murray mine, Mount Nickel mine and Blezard mine. The contacts at these localities dip at angles of 45°, 45°, 29°, 36°, 30° and 50° respectively to the northwestward. Some of these inclinations are illustrated in Fig. 8.

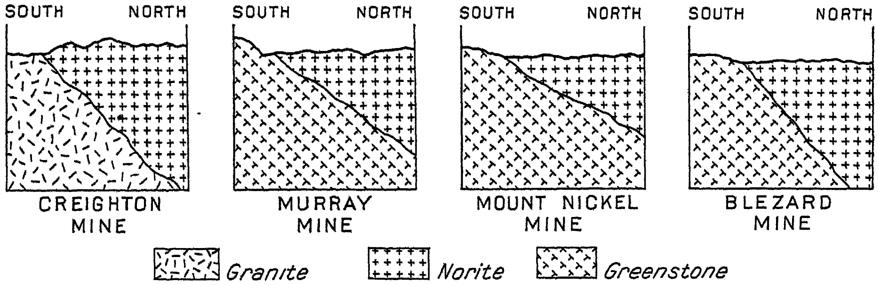

Fig. 8—Cross-sections illustrating sill-like character of the basic edge of the norite-micropegmatite (the so-called nickel eruptive) on the southern nickel range, Sudbury, Ontario. These diagrams show that the norite-micropegmatite has partly a sill-like form.

On the northern nickel range the dip of the intrusive, so far as known, is inwards, towards the basin. The dip at Levack mine has been proved to be 45° to the southeast; and on lot 4 in the fourth concession of Levack township the dip is 45° to 50° to the southeast.

All of the dips so far mentioned refer wholly to the basic (outer) edge of the intrusive. Nothing is definitely known concerning the dip of the acid (inner) edge, since no work or diamond drilling has been done on the inner edge. However, some of the sediments in the basin near the inner part of the intrusive dip inwards, and it has been inferred by certain writers that the dip of the contact of the intrusive follows the inward dip of these sediments. It is prudent, however, to consider that the inward dip of the sediments may have been caused by the faulting down of the basin in one great block. If this happened it would naturally result in tipping the beds so that they dipped inwards. The intrusion of the norite from

below around the faulted block, would intensify this inward dip of the beds. The character and origin of the Sudbury basin is more fully discussed elsewhere in the Report.

The mineralogical and chemical composition of the norite-micropegmatite may now be briefly discussed. It has been shown by Walker, Coleman, and others that the rock has been subjected to magmatic differentiation as it cooled and solidified. The more basic minerals are said to have segregated towards the outer edge, while the more acid minerals segregated towards the inner edge. The basic portion consists of norite, gabbro, diorite and diabase. These rocks appear to grade, through syenite, into granitic rocks, known as micropegmatite, at the inner edge.[1] The micropegmatite contains abundant graphic intergrowths of quartz and feldspar. According to Barlow: "There is no sharp line of demarcation between the acidic and basic portions of the nickel bearing eruptive, but the change, though gradual, is usually sharp enough to enable a boundary to be placed between these two types, with tolerable accuracy."[2]

Analyses of the rock are given in the following table:

Table Showing Chemical Composition of the Norite-Micropegmatite in the Sudbury Area.

——	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
SiO_2	49.90	51.52	56.89	60.15	68.48	64.85	61.93	68.95	69.27	67.76
Al_2O_3	16.32	19.77	19.39	18.23	12.70	11.44	13.03	12.74	12.56	14.00
Fe_2O_3	......	.47	.38	1.51	2.41	2.94	.50	.46	2.89	......
FeO	13.54	6.77	7.11	6.04	4.50	6.02	8.00	5.15	4.51	5.18
MgO	6.22	6.49	2.11	3.22	.74	1.60	1.76	1.57	.91	1.00
CaO	6.58	8.16	8.11	4.01	1.41	3.49	4.02	1.72	1.44	4.28
Na_2O	1.82	2.66	3.31	1.28	3.72	3.92	3.18	3.80	3.12	5.22
K_2O	2.25	.70	1.04	1.68	3.36	3.02	2.80	3.28	3.05	1.19
H_2O	.76	1.68	1.35	.55	1.13+	.78	1.95	1.50	.76	1.01
TiO_2	1.47	1.39	.43	1.34	.61	......	.84	.43	.78	.46
P_2O_5	.17	.10	.11	.23	.20	.24	.32	.20	.06	.19
MnO	trace	trace	.30	.29	.05	trace	.18	.13	trace	trace
BaO	......	......	......	.25	......	......	trace	trace	......	......
LiO	......	......	......	.14	......	......	......	......	......	......
NiO	......	......	......	.17	......	......	......	......	......	......
Cu	......	......	......	.16	......	......	......	......	......	......
S	......	......	......	.54	......	......	.19	......	......	......
Totals	99.03	99.71	100.53	99.79	99.31	98.30	98.76	99.93	99.35	100.29
Specific gravity	3.026	2.832	2.834	......	2.673	2.788	2.757	2.694	2.724	2.709

Nos. 1 and 2—Basic edge on the southern range near Blezard mine. Analyst, T. L. Walker.
No. 3—Near the basic edge on the northern range at Onaping. Analyst, E. G. R. Ardagh.
No. 4—Basic edge near Creighton mine. Analyst, M. T. Culbert.
No. 5—Middle of Onaping section. Analyst, T. L. Walker.
No. 6—Middle of the Blezard-Whitson lake section. Analyst, T. L. Walker.
No. 7—Acid edge on the Onaping section. Analyst, E G. R. Ardagh.
No. 8—Near acid edge on the north shore of Fairbank lake. Analyst, E. G. R. Ardagh.
Nos. 9 and 10—Near the acid edge of the Blezard-Whitson lake section. C. B. Fox, analyst of No. 9; T. L. Walker, of No. 10.

[1] Regarding magmatic differentiation in the norite-micropegmatite Alfred Harker says: "I found no indication of a regular 'composition gradient' in either norite or granophyre, considered separately, while the transitional zone between them has all the characters of a hybrid rock" (Jour. Geol., Vol. 24, 1916, p. 555). This view is at variance with the views of Coleman, Barlow and Walker.

[2] Geol. Sur. Can., Report of the Nickel and Copper Deposits of Sudbury, 1907, p. 85.

Four of the analyses are from the basic edge, two are from the middle of the intrusive, and four are at or near the acid edge of the intrusive. The analyses, in so far as they go, appear to demonstrate that the rock is more basic at the outer edge than at the inner edge, but they also demonstrate, at the same time, that the middle portion of the intrusive is even more acid than part of the inner edge itself. Judging wholly, then, from the analyses, one is not able to say that there is a gradual transition from basic to acid rock as one goes from the outer to the inner edge.

It is desirable, indeed, that more chemical analyses be made to ascertain the precise character of the magmatic differentiation which has taken place in the intrusive. Its general nature is already known. To obtain more information at least six complete sections could be made across the intrusive at strategic points on the northern and southern ranges, specimens being collected at desirable intervals and rock analyses made. Perhaps it might be found, as a result of this work, that the character of the magmatic differentiation is not as regular as it has been considered to be.

This investigation has already been begun in a small way for the Ontario Nickel Commission, the Creighton and Murray mines having been selected for the purpose. At the Creighton mine seven samples of the intrusive were collected at the following distances respectively to the northwest of the Creighton open pit:—140, 200, 300, 750, 1,200, 2,000 and 3,250 feet. The analyses of these samples, shown in the table below, demonstrate that practically no differentiation has taken place in the intrusive for about two-thirds of a mile from its outer edge.

Table, Showing Chemical Composition of Norite at Creighton Mine.

——	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO_2	55.58	51.34	51.80	55.24	54.12	53.26	54.84
Al_2O_3	....	....	....	....	20.18	17.40	....
Fe_2O_3	2.32	2.51	2.80	1.42	2.65	3.35	1.42
FeO	8.03	8.19	7.92	7.07	5.80	5.72	5.67
CaO	7.20	7.40	6.72	6.72	6.72	8.00	7.25
MgO	0.69	3.95	3.36	1.13	3.81	6.62	1.56
Na_2O	2.56	2.18	1.84	2.74	3.17	2.64	2.88
K_2O	0.98	0.80	0.62	1.04	1.52	1.27	1.38
CO_2	0.21	0.32	0.39	0.22	0.40	0.31	0.33
H_2O	2.54	0.78	3.59	1.04	1.74	1.71	1.72
Totals	....	....	....	....	100.11	100.28	....

No. 1—Norite, Creighton mine, 140 feet northwest of open pit.
No. 2— " " " 200 " " " "
No. 3— " " " 300 " " " "
No. 4— " " " 750 " " " "
No. 5— " " " 1,200 " " " "
No. 6— " " " 2,000 " " " "
No. 7— " " " 3,250 " " " "

The result of the chemical analyses at Murray mine also proves that no magmatic differentiation took place in the intrusive for at least 1,900 feet to the northwest of the basic edge. Seven samples of the rock were selected at this

mine at the following distances respectively from the edge of the intrusive: 30, 150, 300, 600, 900, 1,400, 1,900 feet. The analyses are shown in the following table.

Table, Showing Chemical Composition of Norite at the Murray Mine.

——	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO_2	54.84	54.81	55.96	56.10	51.78	54.08	53.08
Al_2O_3	15.82	16.98	21.84	18.72	20.90	16.72	18.54
Fe_2O_3	3.36	1.82	2.84	2.42	1.82	4.90	2.26
FeO	7.02	6.67	5.55	5.78	6.54	5.88	5.28
CaO	5.71	6.96	6.52	6.67	7.52	7.53	7.51
MgO	6.02	6.07	1.48	5.08	5.77	5.23	6.18
Na_2O	3.87	2.99	2.58	2.25	2.82	2.79	3.35
K_2O	2.31	2.18	1.79	1.96	1.84	1.55	2.41
CO_2	trace	0.17	trace	0.22	trace	0.42	trace
H_2O	1.27	1.87	1.19	1.29	1.31	1.08	1.41
Totals	100.22	100.52	99.75	100.49	100.30	100.18	100.02

No. 1—Norite, Murray mine, 30 feet northwest of basic edge.
No. 2— " " " 150 " " "
No. 3— " " " 300 " " "
No. 4— " " " 600 " " "
No. 5— " " " 900 " " "
No. 6— " " " 1,400 " " "
No. 7— " " " 1,900 " " "

In addition to the analyses given above several others were made in order to ascertain the chemical composition of the intrusive at other points. These analyses are shown in the following table.

Table Showing Chemical Composition of Norite or Diorite at Cameron, Evans, Gertrude and Whistle Mines.

——	No. 1	No. 2	No. 3	No. 4
SiO_2	56.86	51.20	59.32	58.86
Al_2O_3	21.62	17.32	16.46	19.54
Fe_2O_3	2.82	5.04	2.52	0.28
FeO	5.29	9.06	5.04	5.76
CaO	6.28	6.76	6.24	6.54
MgO	1.33	4.14	4.12	1.01
Na_2O	2.81	2.32	3.11	2.91
K_2O	1.95	2.14	1.99	2.48
H_2O	0.85	2.15	1.04	2.10
CO_2	0.29	0.25	0.12	0.22
Totals	100.10	100.38	99.96	99.70

No. 1—Norite at Cameron mine.
No. 2—Evans mine.
No. 3—Norite at Gertrude mine.
No. 4—Norite at Whistle mine.

It is of interest to compare the norite-micropegmatite with a similar rock, known as the Nipissing diabase, which occupies comparatively large areas at Cobalt, South Lorrain, Timagami, Gowganda, and elsewhere. These localities are from a few miles to 50 miles or more beyond the norite-micropegmatite. The rocks prob-

Fig. 9—A residential part of the town of Sudbury, Ontario, October 26th, 1916.

Fig. 10—Showing rugged nature of country near Murray mine, Sudbury area, Ontario.

ably both belong to the Keweenawan series and resemble each other in many striking respects. It is not unlikely that they were intruded at the same time and will be proved some day to be one and the same rock. At Cobalt the Nipissing diabase has the form of a sill, while at Sudbury the norite-micropegmatite has a dike-like and sill-like form. Some years ago Miller and Knight compared the two rocks, the following quotation being extracted from their paper.[1]

> These eruptives both show differentiation, or insensible gradations, from such basic rocks as diabase, gabbro and norite to acid rocks with the composition of granite. The differentiation appears to have taken place on a larger scale at Sudbury than at Cobalt and the surrounding region. Although the basic portion (norite) of the nickel eruptive is coarser in grain than the Nipissing diabase, it nevertheless resembles petrographically the latter rock. For instance, in the descriptions by A. P. Coleman and A. E. Barlow, it is brought out that the nickel eruptive sometimes shows "distinct traces and, at times, well marked diabasic or ophitic texture." Furthermore, the basic facies of each contain quartz, usually intergrown in micrographic fashion with an acid plagioclase. When this micrographic intergrowth increases in quantity until it finally becomes the predominant constituent, a rock with the chemical composition of granite results, which is commonly called micropegmatite, granophyre or aplite.

The Sudbury Basin—Its Origin

The Sudbury basin, originally referred to by Robert Bell[2], forms the central part of the Sudbury nickel-copper field. It consists of a very distinct basin about

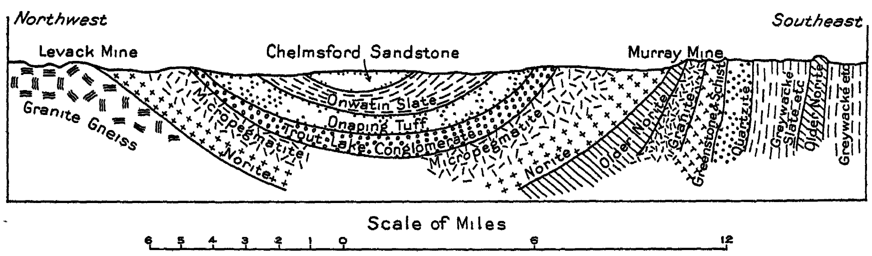

Fig. 11.—Theoretical cross-section through the Sudbury area, illustrating A. P. Coleman's conception of the shape of the norite-micropegmatite, the so-called "nickel eruptive." It is seen that the intrusive is supposed to have the form of a sill. In other parts of the Sudbury area, however, the norite-micropegmatite has a dike-like form; this is true at Crean Hill, Garson, Longyear, and other properties. See Fig. 7, page 115.

36 miles in length and some 16 miles wide. Most of it is covered with clay, sand and gravel. Where the rocks are exposed they consist of sandstones, slates, tuff, and conglomerates of the Animikie series. The basin is often perfectly flat for miles, although it is relieved here and there by gentle undulations in the strata. Its edges are surrounded by rugged hills of conglomerates of the Animikie series, while immediately beyond are somewhat lower hills consisting of the acid edge of the norite-micropegmatite. The latter entirely surrounds the basin. Fig 1.

[1] Eng. and Min. Jour, June 7th, 1913, pp. 1129-1132.
[2] Geol. Sur. Can., Vol. V, Part I, 1890-91, p. 11F.

There is one remarkable feature concerning the basin which requires explanation. Its inner edge is surrounded by the continuous belt of coarse conglomerate already mentioned. Beyond this is the encircling mass of the norite-micropegmatite which completely cuts off the conglomerate. Why this conglomerate does not occur immediately along and beyond the basic edge of the norite-micropegmatite is a question which has occupied the minds of those who have studied the physiography of the basin.

It has been suggested by A. P. Coleman that the norite-micropegmatite was intruded in the form of a sill or sheet which forced its way along the contact between the Animikie series and the underlying older rocks, lifting the former bodily upwards. "The collapse of the foundations of the older rocks," writes Coleman, "caused the cooling sheet of magma to settle into a basin shape, and the nearly flat sediments above it took the same form."[1] Fig. 11. If this solution of the origin of the basin is the true one, then it is an extraordinary thing that not a trace of the conglomerate, not a fragment, not even a pebble has been found below the intrusive. This means that every vestige of the Animikie series was broken off and raised from the uneven surface of the rocks on which the series rested, and that the intrusive was injected precisely along this contact.

As an alternative explanation to Coleman's the following origin of the basin is suggested. This explanation is given because mining operations have shown that the norite-micropegmatite has a gigantic dike-like form as well as a sill-like form, Figs. 7 and 8.

The alternative explanation suggests that the preliminary stage in the formation of the basin may have begun by a great block of the earth's crust gradually faulting down for several thousand feet, carrying with it Animikie sediments. It may be further supposed that the norite-micropegmatite then forced its way upwards and around the faulted block. After the consolidation of the intrusive there followed a prolonged period of erosion, and the rocks were denuded to their present level. The conglomerates, tuffs, slates and sandstones of the Animikie, which extended beyond the outer edge of the intrusive, were thus everywhere carried away by erosive agencies, except the Ramsay lake conglomerate and similar rocks in Falconbridge township. The immense block of these sediments in the basin, however, was preserved from annihilation by the depth to which it had been carried down by faulting.

"Later" Granites

There are several areas of granites which have come to be spoken of as "later," or "younger," granites, meaning that they are later in age than the norite-micropegmatite. The later granites were originally referred to by Adams[2], and afterwards by Walker[3]. Some of these intrusive masses occur within the norite-micropegmatite itself, as, for example, those about two miles northwest of the Murray mine and those near Whitson lake. There are other granites which are met with

[1] The Nickel Industry, Canada Dept. of Mines, 1913, p. 10.

[2] Jour. Gen. Mining Association of Quebec, 1894-95, p. 49.

[3] Quart. Jour. Geol. Soc., London, Vol 53, 1897, pp. 40-66.

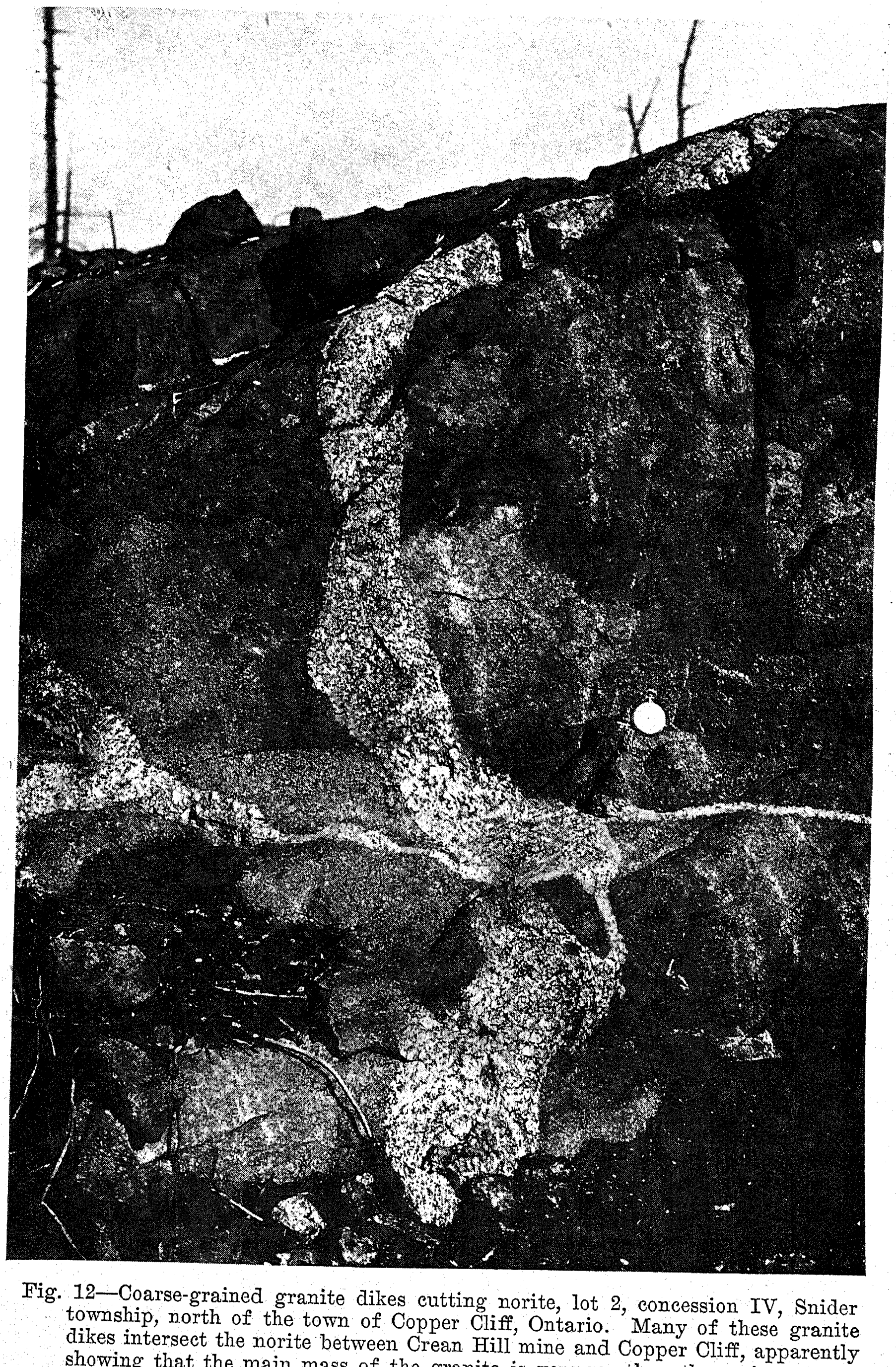

Fig. 12—Coarse-grained granite dikes cutting norite, lot 2, concession IV, Snider township, north of the town of Copper Cliff, Ontario. Many of these granite dikes intersect the norite between Crean Hill mine and Copper Cliff, apparently showing that the main mass of the granite is younger than the main mass of the norite.

at the contact of the norite. One of these occurs to the east of the Murray mine. It has a length of three miles and a width of about a mile, and is believed by Coleman to be "distinctly younger" than the norite-micropegmatite.[1] The evidence for believing that this granite is younger is that the granite sends dikes into the norite.

The age relations of the granite masses referred to in the preceding paragraph are probably as outlined above. There is a larger mass of granite, however, whose age relations to the norite are not agreed upon. This mass is 13 miles long and from one to two and a half miles wide. It occurs as a continuous belt between Copper Cliff and Crean Hill No. 2 and forms the footwall of the Creighton mine. To the writer this granite appears to be younger than the norite because it sends coarse and fine-grained dikes into that rock, Fig. 12. It is only fair to add that Barlow and Coleman have not arrived at a definite decision regarding its age. The importance of knowing its age relation to the norite is great because of the bearing it has on the origin of the ores, pages 131, 151. If, for example, the granite footwall at Creighton mine is younger than the norite, then it was manifestly impossible for the sulphides to have settled from the norite by gravity on this granite.

The views of Barlow and Coleman on the subject of the later granites may be quoted. Barlow's opinions are summed up in the following paragraph:[2]

> The nickel-bearing eruptive, which, in its fresh condition is now referred to as a quartz-hypersthene-gabbro or norite, is decidedly later than, and intrusive through, the green schists and associated diorites. The relations between the so-called 'younger' granite are much more complex and anomalous. For the most part, the nickel-bearing eruptive has cooled against the granite, as may be seen at the junction between these two rocks, on the west side of the large pit known as the No. 2 mine at Copper Cliff. Here the norite is distinctly finer in grain at the immediate point of contact, this rock growing visibly coarser farther away from the line of junction. This cooling of the norite against the granite, and the production of a finer-grained or chilled selvage, is especially well seen in the vicinity of the openings made by the Vivians on lot 9, concession VI, of McKim township. On the other hand, in some localities, certain dikes or apophyses of the granite seem to penetrate the norite, as may be noticed along the line of junction to the northwest of No. 2 mine, at Copper Cliff; while the intrusive nature of the granite, and its apparently later age in relation to the norite, is quite marked to the north of Clarabelle lake, where the line of junction between the two rocks is well exposed for a considerable distance. Besides, near the Creighton mine, the granite becomes decidedly more basic in the vicinity of the norite, and a certain zone or belt is formed by the commingling of the material of both rocks, as a result of actual fusion. It has been suggested that the granite and norite may have been differentiates of the same magma, but a more reasonable explanation would seem to be that their periods of intrusion were so closely synchronous, that they overlapped in their time of crystallization, and that the later secretions from the slower cooling granite magma, forced or ate their way into the norite in certain places.

Coleman's views on the subject of the later granites are given in the following quotations:[3]

> As explained before, the nickel-bearing eruptive is younger than the series of sediments which rest upon it, but it is by no means the latest eruptive of the district. Penetrating its edge near Murray mine and Copper Cliff there are flesh coloured to grey, medium

[1] Ont. Bur. Mines, Vol. XIV, Part III, pp. 83, 14, 15, 82, 123, 124.
[2] Geol. Sur. Can., Vol. XIV, Part H, pp. 53, 54.
[3] Ont. Bur. Mines, Vol. XIV, Part III, p. 14.

grained granites, and within the eruptive north of Murray mine and near Whitson lake, as well as in other places, there are pale or flesh-coloured granitic rocks, probably later dikes or irregular bosses; so that the main laccolithic sheet was followed by more acid flows of a somewhat later age, but perhaps before the sheet had completely lost its heat.

. . . .

Besides the granite and granitoid gneiss of the Laurentian, which are much older than the sheet of nickel eruptive and underlie it, there are coarse and medium-grained granite and granitoid gneiss, probably not very different in age from the nickel eruptive, but sometimes a little older and sometimes younger. As they occur in bands parallel to the southern nickel range and at no great distance from it, they may be supposed to have some connection with the nickel rock in origin, perhaps having segregated from the same magma before or after the magma of the laccolithic sheet reached its present position. The coarse textured granitoid gneiss, often porphyritic, is, in my opinion, generally older than the nickel rock.[1]

. . . .

While the coarse granitic rocks are generally older than the norite, there is a medium grained flesh-red granite covering considerable areas from near Elsie to Little Stobie, which is undoubtedly later in age, since it penetrates the edge of the norite at Murray mine.[2]

. . . .

Later than the "older norite" lava streams came eruptions of deep-seated acid rocks, coarse granite, syenite and granitoid gneiss, generally flesh-coloured, and frequently carrying off fragments of the greenstones just mentioned and also of greywacké, and sending dikes into these rocks. The most important area of granite runs from Copper Cliff southwest to near Crean Hill, as a band from one to two and a half miles wide, forming the country rock of the nickel range for more than half of this distance, which includes the famous Creighton mine. These rocks are of various textures and ages, some being undoubtedly older than the nickel eruptive and others younger.[3]

. . . .

The granite to the south [near the Vermilion river] becomes coarse and red and markedly porphyritic as one approaches the river, and is probably older than the norite, though this is not positively proved.[4]

The preceding quotations show that the age relation of the granite, between Crean Hill and Copper Cliff, to the norite-micropegmatite is not positively proved according to Barlow and Coleman. If it can be demonstrated that the Copper Cliff offset (dike) is part of the norite-micropegmatite then a portion at least of the granite is older than the norite-micropegmatite, since the Copper Cliff offset is undoubtedly younger than the granite. This offset, however, is separated by a lake from the main mass of the norite.

It may be added that at many places between Copper Cliff and the Crean Hill No. 2 there are irregular, elongated masses of greenstone intervening between the granite and the norite-micropegmatite. These greenstones may have acted as a buffer, so that the norite was protected from the metamorphosing effect of the intrusive granite. It is otherwise difficult to explain why the norite has been so little altered by the granite, except for a zone several feet more or less in width along the contact.

On the northern nickel range, at the Levack and Strathcona mines, for example, there are granites and granite gneisses which are undoubtedly older than the norite-micropegmatite.

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[1] Ont. Bur Mines, Vol. XIV, Part III, p. 123.

[2] Ibid, p. 124.

[3] The Nickel Industry, Department of Mines, Canada, 1913, p. 8.

[4] Ibid, p. 53.

THE ORIGIN OF THE SUDBURY NICKEL-COPPER ORES

It has been remarked that in the case of many ore deposits throughout the world which have been closely studied no agreement has yet been reached regarding the source of the ores, or the manner in which they arrived at their present positions. Certain authorities, for example, consider that the Rio Tinto pyritic deposits in Spain, among the largest and oldest known of copper occurrences, are sediments, while others believe they are magmatic segregations—two widely differing theories. Then there are, even yet, different opinions as to the origin of the famous Rand gold deposits. The great Sudbury nickel-copper deposits have likewise proved, from the time they were first discovered, a source of controversy regarding their origin, and it is likely that many years will elapse before unanimity will be reached in respect of their manner of formation.

Two main theories have been proposed to account for the origin of the Sudbury deposits. One suggests that the nickel, copper and iron sulphides cooled and segregated from a molten condition like igneous rocks. This is known as the igneous or magmatic segregation theory; it is, indeed, what may be called the fashionable theory of the day, in so far as it concerns the Sudbury ores. The other theory accounts for the origin of the deposits by supposing that the ores have been formed by heated waters circulating through crushed, brecciated, fissured and sheared zones. The waters carried in solution the components of nickel, copper and iron sulphides. These two theories regarding the origin of mineral deposits in general were the cause of controversies throughout Europe long before the Sudbury deposits were worked.

The theory that certain ore deposits cooled and solidified from a molten condition like igneous rocks is a very old one indeed. It was proposed by Fournet and others sometime prior to 1838. The language used in explaining the theory was clear and unmistakable. Veins "were formed similarly to the igneous rocks, by means of an igneous fluid injection"; and, again, "the material has been introduced by an igneous fluid injection and has then solidified in the fissures."[1]

This is not only a very old theory, but it was at one time a very commonly accepted one. Von Cotta has remarked that when the igneous origin of many rocks which occur as dikes had once been recognized, many persons were inclined, during the first half of the nineteenth century, to consider all lodes as igneous fluid injections.[2]

The theory that ore deposits were formed by heated circulating waters is also a very old one—older than the theory of igneous origin. It appears to have first been clearly defined by Lasius in 1789. The waters were believed by Elie de Beaumont to have been derived from volcanic exhalations.[3] This remarkable statement was made in 1846.

[1] Von Cotta's Treatise on Ore Deposits, Prime's Translation, 1870, pp. 71, 75, 76.

[2] Ibid, p. 75.

[3] Bulletin de la Société Geolog. de France, 2nd Series, Vol. 4, p. 1349; Von Cotta's Treatise on Ore Deposits, p. 73.

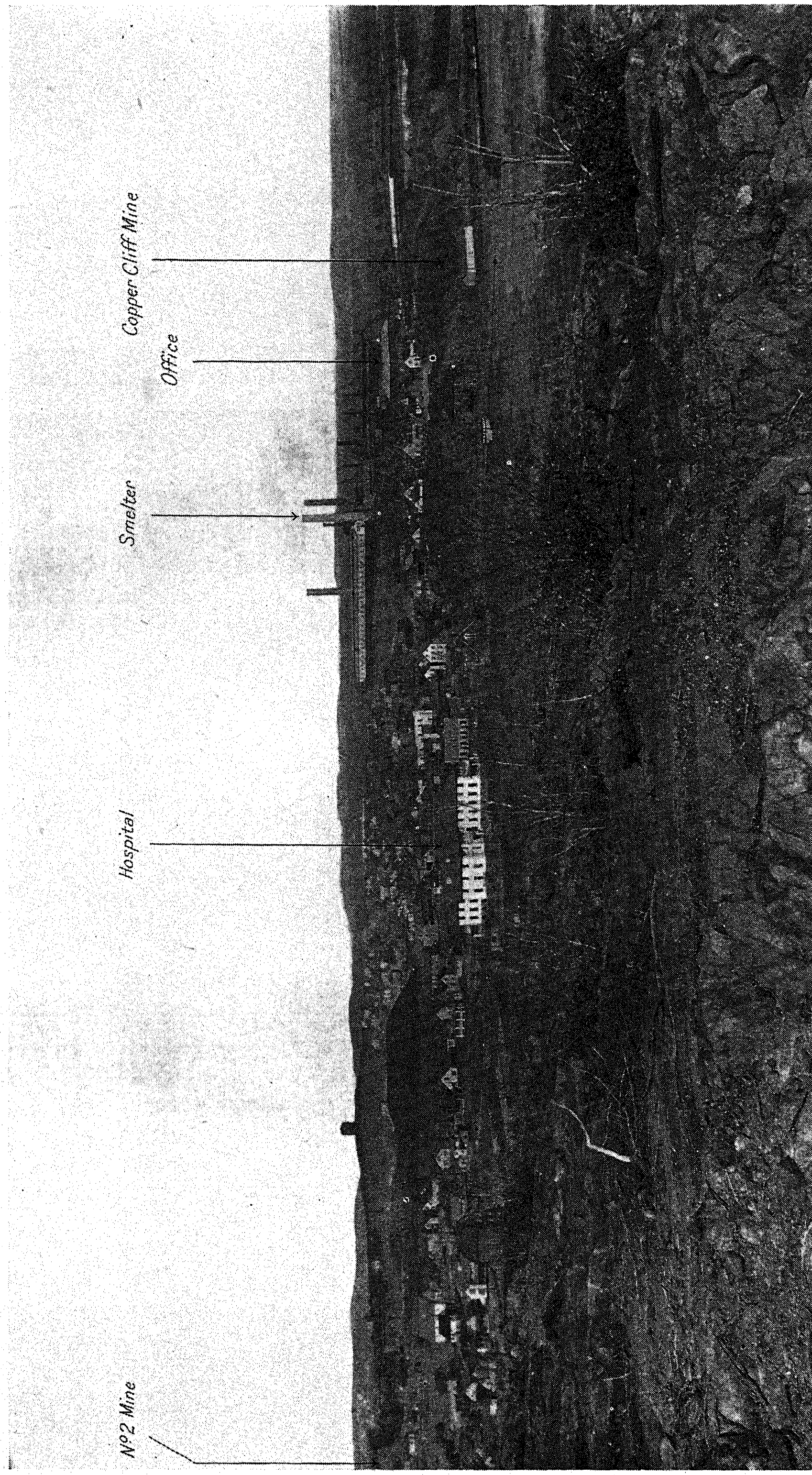

Fig. 13—Town of Copper Cliff, Sudbury area, Ontario, August 13, 1916. The nickel-copper ores from the mines of the Canadian Copper Company are smelted here.

Igneous or Magmatic Segregation Theory

The igneous origin of the Sudbury ores has been advocated by Bell, Walker, Barlow, Coleman, and many others. Coleman has published more information regarding the character and origin of the deposits than has any other worker, and his views may therefore be given rather fully, especially as his suggestions have met with much recognition. He believed that:

> . . . the ore bodies form part of the edge of a great eruptive sheet having a length of 36 miles, a breadth of 16 miles, and a thickness of a mile and a quarter. While cooling, this molten sheet underwent magmatic segregation in which gravitation played a large part, so that the heaviest ingredients, the ores, sank to the lowest points, merging upwards into norite, the next heaviest rock, which passes upwards into granite, the lightest rock of the sheet.[1] [Fig. 11.]

This conception of the formation of ore bodies of igneous origin was foreshadowed in a crude but remarkable manner by D. C. Davies prior to 1888. Speaking generally of ore bodies of this type, although not referring specifically to Sudbury, Davies wrote:

> The eruptive mass would also be itself charged with whatever metals prevailed in it as it lay quiescent in the furnace below. In the process of cooling, especially if this were slow, this heavy metallic matter would sink to the bottom of the overflowing mass and gravitate towards hollows in the underlying rock. This affords an illustration of the way in which a contact deposit lying underneath an eruptive rock may have been produced.[2]

The conception of the settling of sulphides by gravity was also advanced many years ago in connection with the Meinkjar nickel mine in Norway.[3] Bell likewise suggested this idea regarding the Sudbury ores.[4] "If the diorite," Bell wrote, "flowed out originally upon the nearly horizontal surface of the other rocks, the constituents of the ore which it contained may have sought the lower portion of the mass." The theory was later applied by Coleman, as shown in the above quotation, to explain the formation of the Sudbury ores.

While Coleman believed that the theory of magmatic segregation accorded best with the facts, he considered that there had been some subsequent rearrangement of the ores by solution and redeposition in all the deposits.[5] Indeed, he went so far as to say that a few deposits, such as the Worthington and Vermilion mines, may have been formed principally through the action of heated water circulating along fissures at distances, sometimes miles, away from the edge of what he called the great eruptive sheet or sill[6]

Coleman divided the deposits into the following types:

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[1] Jour. Geol., Vol. 15, 1907, pp. 759-782; Ont. Bur. Mines, Vol. 12, 1903, pp. 276-281.

[2] A treatise on Metalliferous Minerals and Mining, D. C. Davies, 4th ed., 1888, p. 30.

[3] Ore Deposits, by Beyschlag, Vogt and Krush, 1914, Truscott's translation, Vol. I, p. 292.

[4] Bull. Geol. Soc. Am., Vol 2, 1890, pp. 125-137.

[5] Ont Bur. Mines, Vol. 14, 1904, Part III, p. 17.

[6] Ibid. p. 19.

Marginal—

a. "Dipping toward the axis of the basin—ores with comparatively little rock and more than twice as much nickel as copper." Examples: Creighton, Elsie, Murray.

b. "Faulted marginal—irregular in shape and character—usually mixed with much rock and carrying as much copper as nickel, or sometimes more." Examples: Crean Hill, Garson.

Offsets (dikes)—

a. "Columnar offsets, roughly cylindrical bodies nearly vertical and going to great depths. Ore usually rich in copper and the precious metals." Examples: Copper Cliff, No. 2.

b. "Parallel offsets—not columnar, but sheet-like, dipping inward toward the basic edge. Ore like that of the usual marginal deposits." Examples: Frood, Stobie.

He advanced the following arguments to prove that the ore bodies were formed by magmatic segregation:[1]

A. "The ores are everywhere associated with the norite of a single eruptive sheet. No ore occurs without norite. No long stretch of the lower edge of the norite or its dike-like offsets is entirely devoid of ore.

B. "Norite and ore are mixed in every degree from rock enclosing scattered particles of ore, to pyrrhotite-norite in which ore and rock are in equal amounts, and finally to almost pure ore with a few rock-forming minerals scattered through it. This relationship is found at every mine. Norite spotted with ore is sometimes found in bands a long distance from the nearest ore body and separated from the basic edge by rock free from ore.

C. "The adjoining rock, granite, gneiss, greenstone or greywacké, is never spotted with ore, and separated bodies of ore are never enclosed in it, but veinlets of ore may penetrate the country rock, and almost always blocks of it are enclosed in the ore. The shattering and crushing of the country rock took place when the nickel eruptive forced its way between the upper sediments and the lower crystalline rocks, and the heavier and probably more fluid sulphides filled all the spaces thus opened. There are often clean walls of country rock against large bodies of pure ore.

D. "The freshest norite is generally close to the ore bodies and is often shotted with ore. The best preserved hypersthenes at the Murray, Creighton and Gertrude mines are in sections containing sulphides and not in specimens free from sulphides at a distance from the mines. No considerable amount of rearrangement caused by water could have taken place without changing so susceptible a mineral as hypersthene into secondary minerals.

E. "The marginal ore bodies show hardly a trace of hydrothermal or pneumatolytic action. There are seldom any of the minerals usual in deposits formed by water except very small quantities of quartz and calcite, and these are often in seams cutting the ore and evidently of later formation. There is no banding such as one finds where cavities are filled with minerals deposited from solution; nor are there concentric structures about the rock fragments enclosed in the ore.

F. "The deposits are extremely uniform, as shown by Dr. Barlow, a fact hard to account for in mines scattered along a length of 35 miles with entirely different country rocks on one side, unless they have had a single source, the norite, which is as monotonous as the ores themselves.

G. "The largest ore bodies are where bays of the norite project into the country rock or on offsets from such funnel-like bays; there is seldom a deposit of importance along a straight margin; and no ores are found on parts of the margin which project inwards instead of outwards. This is intelligible if the ore settled into the hollows under the molten sheet, but quite unaccountable if it was brought in solution from elsewhere along the channels furnished by the contact."

[1] Ibid, pp. 18, 19

There are some objections to the theory of magmatic segregation. Before giving these objections, however, it may be pointed out that all observers agree there is some connection between the origin of the ores and the norite, just as there is, for instance, between the cobalt-silver ores and the diabase of Cobalt and the surrounding region.

In *argument B* it is stated that ore and norite are mixed in every degree from rock enclosing particles of ore, to pyrrhotite-norite, in which ore and rock are in equal amounts, and, finally, to almost pure ore with a few rock-forming minerals. While it is true that norite and ore are "mixed," as Coleman points out, it is also true that granite and ore, greenstone and ore, and quartzite and ore are also "mixed" in the same manner. Nevertheless in marginal deposits it has been found that the commercial ore bodies occur almost wholly in the rocks adjacent to the norite, not in the norite. The contact between commercial ore and norite is generally a comparatively abrupt one. This is particularly true at the Creighton mine where the massive sulphides occur more or less sharply defined against the lean "spotted" norite.[1] Indeed, at this mine it may be said that as soon as the norite hanging-wall is encountered the commercial ore body ends.

In the case of *argument C* it may be said it has since been found that granite, gneiss, greenstone, greywacké, schist, quartzite, and other rocks are "spotted" with ore. The "spotted" granite at Creighton mine is quite fresh. It has, further, been pointed out in the preceding paragraph that the commercial ore bodies do occur almost wholly in the adjoining rock, the conspicuous example being the Levack occurrence. The Levack ore body occurs entirely in the granite gneiss, and is separated from the norite by 40 to 220 feet of granite gneiss, Fig. 40.

It is urged in *argument D* that the norite is too fresh to have allowed the sulphides to have been introduced by solutions. The norite is very fresh at most deposits, but at such occurrences as the Garson and Victoria mine it is often so badly decomposed and altered to a schist that it is difficult to distinguish it from other altered rocks. At deposits where it has remained fresh, the explanation seems to be that the rocks generally were but slightly affected by the introduction of sulphides, as the granite at the Creighton, for instance, is as fresh as the norite.

Probably at the time when *argument E* was brought forward it was not known that, at such deposits as the Garson, Victoria and Crean Hill, quartz and calcite, particularly the former, are present in such quantities as to suggest that the ores were deposited from solutions. At the Garson mine, for example, some 35,000 tons of quartz have been mined and shipped, and there still remain in the ore body many thousands of tons of this mineral.

In the case of *argument F* it is agreed by those who support the theory of deposition from heated waters that the norite, or the reservoir from which it was intruded, was the source of the ores and of the heated waters.

Finally, it may be pointed out, in the case of *argument G*, that there are too many notable exceptions to the statement that the largest ore bodies are found "where bays of the norite project into the country rock." One of the largest ore bodies in the entire area, the Levack deposit, does not occur in a "bay" in the norite. This is also true of the Crean Hill mine, the second largest producer in 1916, belonging to the Canadian Copper Company.

[1] See pages 146, 147.

In addition to the objections above outlined, there are other reasons which make it difficult to accept the theory of magmatic segregation—particularly that variety of segregation in which gravity is thought to have played an important part. It has, for example, been found that in many deposits fragments and blocks of norite are found cemented together by sulphides, Figs 24, 25. It is, therefore, evident that the norite had solidified before the sulphides were introduced. Microscopic studies also bear out the fact that the sulphides had crystallized later than the rock-forming minerals of the norite. This being true, it is not easy to accept the statement that the sulphides settled through a molten norite magma.

In another part of this report, pages 122-125, it is shown that the granite foot-wall at the Creighton mine is younger than the norite hanging-wall. This age relationship between the granite and norite also presents an obstacle to a belief in gravity segregation.

Little or no magmatic differentiation has taken place in the norite at Creighton or Murray mines. Chemical analyses of the norite at these two mines show that the rock is remarkably uniform along the basic edge. At the Creighton, for example, for a distance of 3,250 feet from the contact there is scarcely any change in its composition.

Even the most ardent believers in magmatic segregation declare that heated waters may have played the principal role in the formation of some deposits—the Worthington, Vermilion, and perhaps the Crean Hill.[1] There appears to be, however, no essential difference between such ore bodies as the Worthington and Crean Hill, on the one hand, and deposits like the Creighton and Garson on the other. It would seem that an explanation of the formation of one class would also account for the origin of the other. All of the commercial ore bodies are of the same monotonous character; that is to say, they consist largely of rock fragments cemented together by sulphides. "Spotted" rocks, i.e., those with "spots" and "blebs" of sulphides about the size of peas, occur at all the deposits.

Theory of Deposition of Ores from Heated Waters

The difficulties confronting a belief in magmatic segregation seem to make it necessary to turn to an alternative explanation as to the formation of the ores. That explanation is the one which suggests that the ore bodies were formed by the circulation of heated, mineral-bearing waters through openings and lines of disturbances—crushed, brecciated, fissured and sheared zones. The heated waters contained in solution the components of nickel, copper and iron sulphides, and probably to a minor extent lime, magnesia, silica, and other materials. The nickel, copper and iron were precipitated mainly as pentlandite, chalcopyrite and pyrrhotite. Regarding this explanation of the origin of the ores Kemp,[2] although a believer in magmatic segregation, has remarked: this theory is a time-honoured one; it involves nothing unreasonable, and has the support of some of the ablest investigators.

[1] Ont. Bur. Mines, Vol. 14, Part III, p. 19, and The Nickel Industry, Mines Branch, Ottawa, 1913, p. 52, A. P Coleman. Economic Geology, Sept.-Oct., 1915, pp. 536-542, T. L. Walker.

[2] Ore Deposits of the United States and Canada, J. F. Kemp, 1903, pp. 61, 62.

It suggests that the rocks have been crushed, brecciated, fissured and sheared or otherwise disturbed. In marginal deposits, these disturbances took place mainly in the rocks adjacent to the norite and only to a minor extent in the norite itself. In offset deposits (dikes) the crushing did take place largely in the dikes. There is ample proof of these disturbances, since the ore bodies consist mainly of fragments and blocks of rocks of all sizes, cemented together by sulphides, Figs 14, 20. These fragments possess great variety in shape, and they consist of granite, greenstone, norite, gabbro, quartzite, greywacké, and other rocks. They may be almost wholly replaced or impregnated by sulphides; the process of replacement is particularly well seen at the Creighton mine, where all gradations are found between coarse-grained granite fragments that are slightly replaced by pyrrhotite, chalcopyrite or pentlandite, to ore in which only a few specks of granite remain. Replacement or impregnation has also taken place in fragments of norite at Creighton.

Fig. 14.—Character of ore at Levack mine, third level, Sudbury area, Ontario. Black represents sulphides; white represents granite-gneiss. Width of face 4 feet.

The walls of the marginal and offset ore bodies are also universally replaced or impregnated by ore whether they consist of norite, granite, greenstone, or any other rock. Usually this process of replacement or impregnation is accompanied by little or no alteration of the rocks, this being particularly noticeable in the case of norite and granite at Creighton. The walls of ore bodies such as the Garson and Victoria, however, have usually suffered great alteration. Norite and greenstone at these two deposits are often entirely altered to schists and gneiss.

In the case of offset deposits (mineralized dikes) the process of crushing and brecciation has also taken place. The Worthington and Howland ore bodies are examples of this type of deposit. The sulphides have been introduced through the crushed offsets, the latter being partly replaced or impregnated by the ore.

There is not lacking direct evidence to show that the sulphides were introduced by heated waters. Such minerals as quartz and calcite are of common occurrence, as previously mentioned, at the Garson, Crean Hill, Victoria and Chicago mines.

Quartz is found in large quantities at the Garson. Quartz and calcite are commonly formed by deposition from circulating waters. In the majority of deposits, however, these two minerals constitute a very unimportant part of the ore bodies.

To the question: "Where did the heated, circulating waters, which formed the ore bodies, come from?" it must be replied that it is not possible to give a definite answer. It may be pointed out, however, that, prior to the formation of the ore bodies, igneous activity, i.e., the eruption of masses of igneous rocks, took place on a stupendous scale in the Sudbury area. One of the earliest eruptions appears to have been the greenstone (sudburite). This was followed by intrusions of gabbro, after which the norite-micropegmatite was injected into the crust of the earth. Then came the intrusions of "later" granites. Thus there were at least four distinct eruptions of igneous rocks prior to the formation of the ore bodies. Without doubt each one of these eruptions gave off heated waters during and after its injection. Inasmuch as the ore bodies are more closely associated with the norite than with any other rock, it would appear that the heated waters given off by that immense mass of igneous material, or from its deeper seated, molten reservoir of rock, may have played an important part in the formation of the ores.

Finally, in speculating as to the origin of the ore-bearing waters which formed the Sudbury deposits, there is the possibility that these solutions may have emanated directly from the same deep-seated reservoir of igneous material which gave off the successive intrusions of greenstone, gabbro, norite-micropegmatite, and "later" granites.

In the preceding paragraphs the discussion on the origin of the ores has been given in order to bring out both sides of the question, and to show that unanimity of opinion has not yet been reached.*

* The most recent publication on the Sudbury deposits, and similar occurrences in Norway, Sweden, South Africa, California and elsewhere, is by C. F. Tolman, Jr., and Austin F. Rogers This publication was received while the Report of the Ontario Nickel Commission was going through the press. Tolman and Rogers do not appear to have visited the Sudbury area in order to study the deposits in the field. Their work was done in the laboratory. Nevertheless the writer is in entire agreement with their statement that the ore bodies were not formed by the sinking of the sulphides in the molten magma. Objections to the theory of gravity segregation were pointed out by the writer in the Engineering and Mining Journal for May 6th and September 23rd, 1916. Tolman and Rogers concluded that ores of this class throughout the world have been introduced at a late magmatic stage as a result of mineralizers, and that the ore-minerals replace the silicates. They regard sulphur as a mineralizer of importance. They believe that a sulphide melt, similar to that in the reverberatory furnace, does not exist after the final consolidation of the silicates of the magma. They believe that the "molten" condition of the sulphides must be due to mineralizers in such amounts that the characteristics of the mixtures are those of a high-temperature solution and not a melt. They find no support whatever for the idea that the sulphides separated as molten mixtures and solidified later. Regarding the Sudbury ores in particular these authors state that the ore bodies were not formed by the sinking of the ores in the molten magma. Summing up their conclusions in respect of the Sudbury ores Tolman and Rogers say: "Although the ores are believed to be magmatic they have been formed at the end of the magmatic period by the replacement of the silicates." (Leland Stanford Junior University Publications, University series, 1916, "A Study of the Magmatic Sulphide Ores." Eng. and Min. Jour., Feb. 3rd, 1917, pp. 226-29.)

DESCRIPTION OF SUDBURY ORE BODIES

During the latter part of the summer of 1916 eight mines were producing in the Sudbury area, namely, the Crean Hill, Creighton, No. 2 and Vermilion of the Canadian Copper Company, and the Garson, Levack, Victoria and Worthington of the Mond Nickel Company. Development work was being done on the Murray mine of the British America Nickel Corporation. The Mond Company pumped out the Blezard mine and were testing it by means of diamond drills. Important diamond-drilling operations were also being carried on by the Longyear syndicate in the township of Falconbridge. It may be added that, in addition to the ore obtained from the mines mentioned, the Mond Nickel Company was purchasing a comparatively small quantity of ore from the Alexo mine, which lies beyond the boundaries of the Sudbury area.

Descriptions of the deposits at the properties mentioned, where ore was being produced in the summer of 1916, will be given under the heading of Working Mines. Afterwards descriptions will be given of the deposits that were lying idle.

An estimate of the tonnage of ore developed in the Sudbury area is given on a preceding page.

WORKING MINES

The Crean Hill Ore Body

The Crean Hill mine is located on lots 4 and 5 in the fifth concession of Denison township. It is served by the Algoma Eastern railway, and is distant from the town of Sudbury about 18 miles. The ore reserves at the end of 1916 amounted to about 2,000,000 tons.

The oldest rocks in the vicinity of the deposit are quartzites and greywackés belonging to the Timiskaming or Sudbury series. They constitute a relatively small part of the formations and appear to be mainly inclusions in the greenstone. The greenstone, which is younger than the quartzites and greywackés, is a fine or medium-grained rock of about the composition of diorite or other closely related type. It is the most important rock in connection with the Crean Hill mine because the ore occurs largely in it. After the greenstone there followed the intrusion of the norite, and, when it solidified, brecciation, crushing and shearing took place along the contact, but mainly in the adjacent greenstone. Then followed the introduction of the sulphides along this crushed and disturbed zone, forming the ore body. When the formation of the deposit was complete, it was fissured, and a dike of trap rock was injected through it and the adjacent greenstone and norite. Finally, as is often the case in the deposits throughout the area, fissures were again formed and dikes of olivine diabase were injected, intersecting the trap dike, ore body, norite, greenstone, and quartzite.

In addition to the rocks above mentioned there are dikes and irregular intrusions of granite intersecting the greenstone and norite.

The shape and size of the main ore body are shown in the composite plan, facing page 134, which gives the outlines on the surface and on various levels down to the ninth. The main ore body has been worked to a vertical depth of about 750

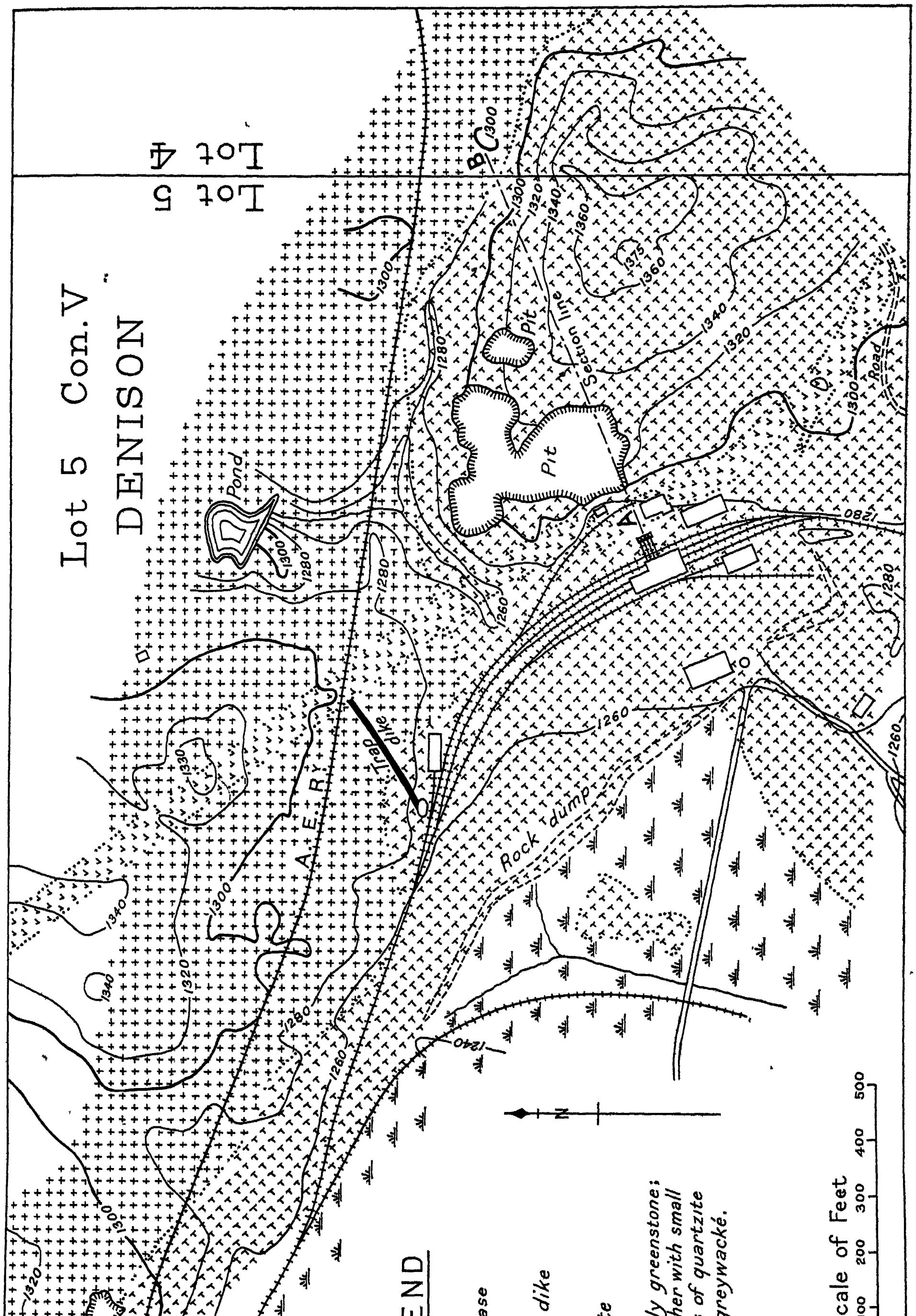

Fig. 15—Geological map of Crean Hill mine, Sudbury area, Ontario. After A. P. Coleman. The plan shows the location of cross-section A. B.

feet (the ninth level) below the collar of the shaft. On the surface it has a maximum dimension in a north and south direction of more than 300 feet, but with depth it appears to become smaller, the width being about 100 feet on the ninth level. On the fifth level, which is about 300 feet vertically below the collar of the shaft, another ore body is being worked at a distance of about 500 feet westward from the main deposit. This ore body is smaller than the main deposit. There is a third deposit about 1,600 feet westward from the main ore body. It has been worked by an open pit, the latter having a length of 150 feet, a width of 45 feet, and a depth of 25 feet. No work was being done here in the summer of 1916.

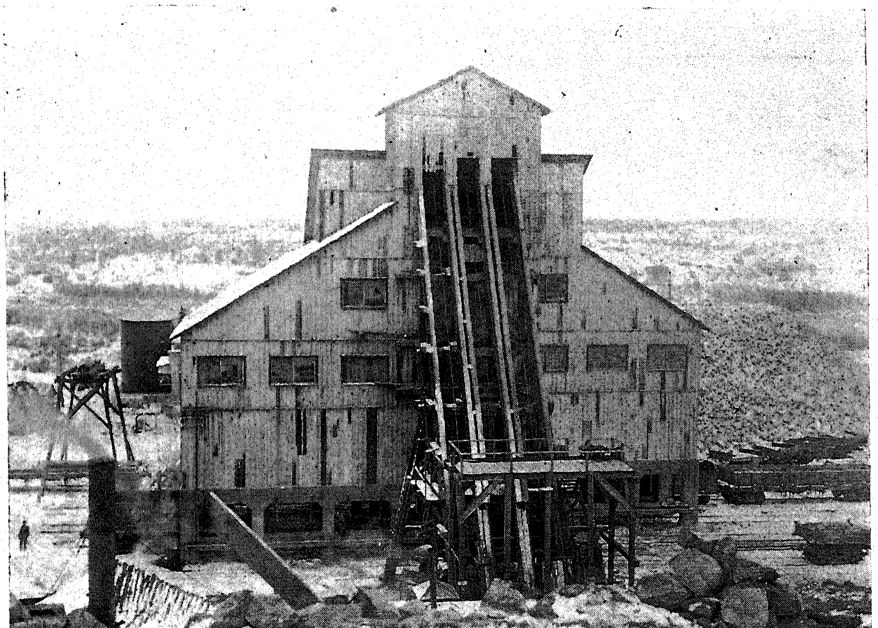

Fig. 16—Crean Hill rock house and shaft, November 24th, 1916, Sudbury area, Ontario.

The main ore body occurs largely in the greenstone. Down to about the fourth level the ore occurs wholly in greenstone, but at this level norite forms the north wall of the deposit, and at lower levels some ore does occur in the norite. The second ore body, which is being developed on the fifth level some 500 feet west of the main ore body, occurs about at the contact of greenstone and norite, some commercial ore being found in the norite, but mostly in the greenstone and to a certain extent in quartzite. The third ore body occurs at the contact of norite and greenstone, mainly in the latter.

The mineralized zone in which the ore bodies described above occur has a length of about two-thirds of a mile or more and a maximum width of 500 or 600 feet. It occurs at the contact of norite and greenstone, but mainly in the greenstone. The ore bodies consist largely of crush-conglomerates and crush-breccias of greenstone. The fragments and blocks of these crush-conglomerates and crush-breccias are cemented together by sulphides. The sulphides also occur in veinlets and in disseminated grains.

The contact between the norite and greenstone has been encountered at various places in the workings, and its angle of dip has been determined. In the

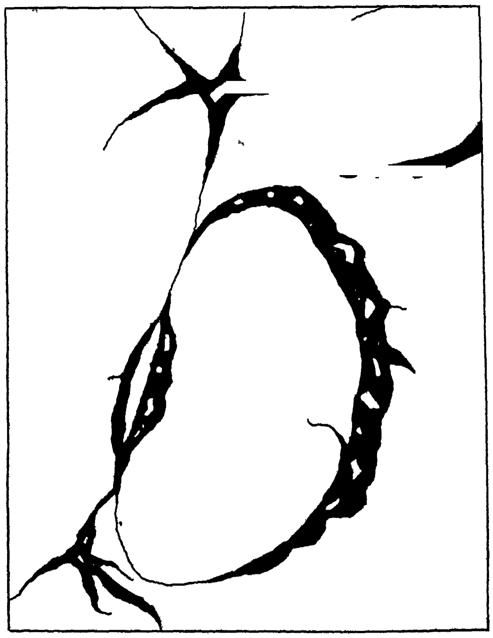

Fig. 17—Showing character of ore at Crean Hill mine, second level, Sudbury area, Ontario. White represents greenstone; black represents ore. The width of the face indicated in drawing is 15 feet.

shaft section, for example, Fig 18, the norite dips to the southward under the greenstone at an angle of 50 or 60 degrees to about the sixth level, below which it becomes about vertical. Some 500 feet westward from the main ore body the angle of dip is 80 degrees, more or less, to the northward. In the pit 1,600 feet westward from the main ore body the contact appears to be vertical.

In several parts of the mine well defined faults have been encountered. They consist of crushed zones averaging 2 or 3 feet in thickness, the fragments being made up of brecciated rock and ore and much soft, clay-like material. Two of these faults, Fig. 18, intersect the shaft between the third and fourth levels.

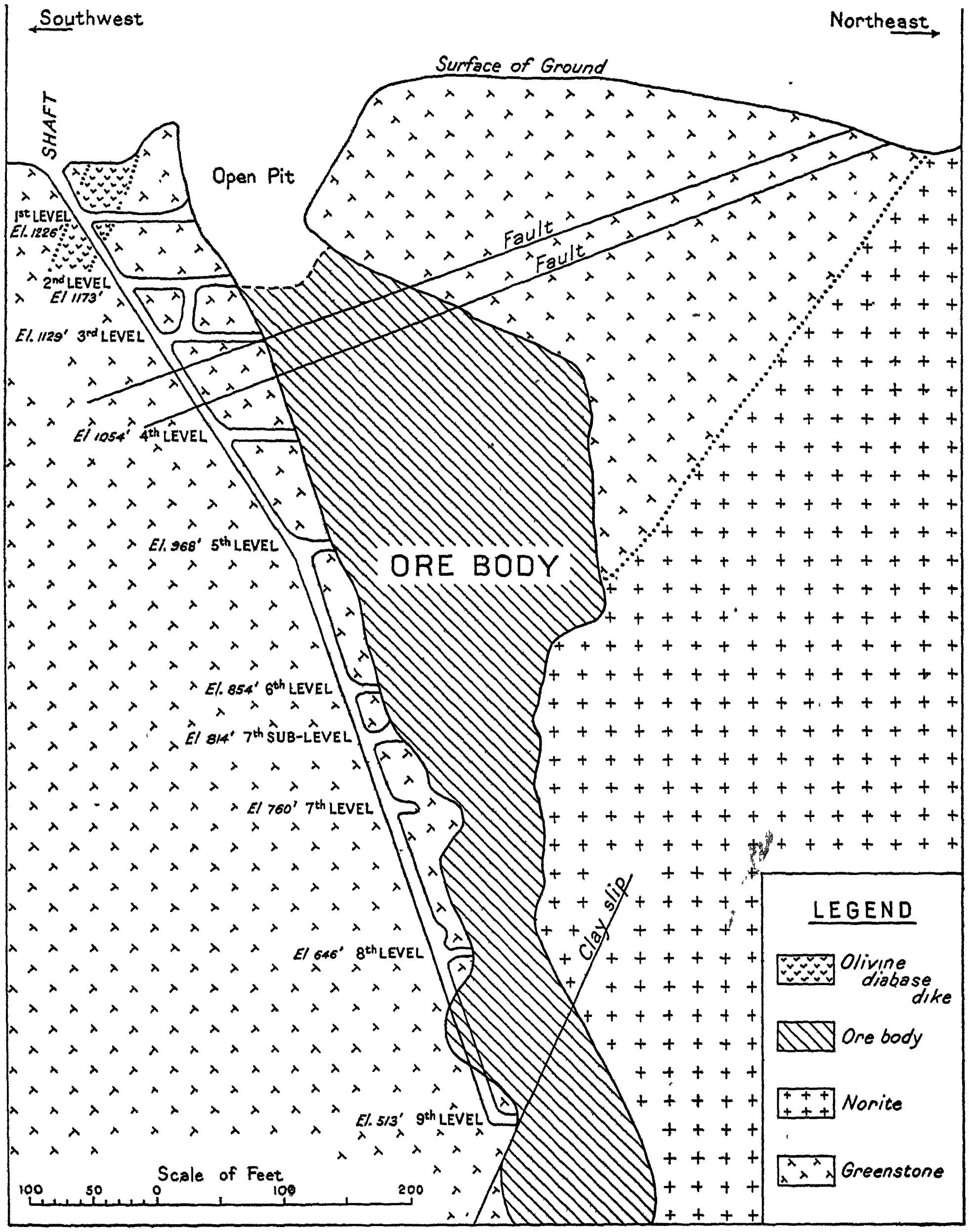

Fig. 18—Cross-section A B, see Fig. 15, through Crean Hill ore body along the shaft section, Sudbury area, Ontario. The upper portion of the deposit occurs entirely in the greenstone, while the lower portion occurs at the contact of greenstone and norite, partly in the greenstone, partly in the norite. There appears to have been little or no displacement of the ore body along the faults in the upper part of the deposit. From cross-section by the Canadian Copper Company.

They rise towards the northeast at an angle of about 20 or 25 degrees, and appear on the second level in the great open pit. It is evident that these two faults were formed long after the deposition of the ore body. No trouble has been experienced in following the ore on opposite sides of both faults. The throw, if appreciable, has not been determined. At no place in the mine have these two faults, or any others, been found in contact with the olivine diabase dike at the west side of the open pit. It would appear, however, that the faults were formed after the dike had solidified. The reason for believing this is that the material in the faults is recent-looking, soft, and loosely cemented together, and it would seem that, if the faults were older than the dike, molten material from the latter would almost certainly have found its way through this loosely cemented material. It may be

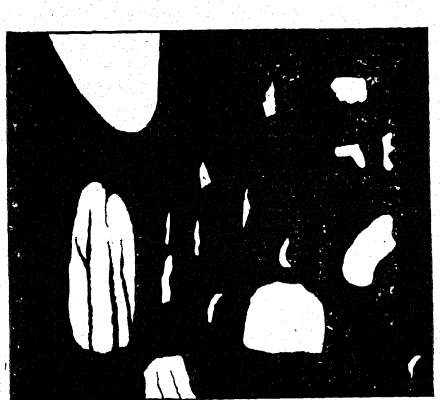

Fig. 19—Showing character of ore at Crean Hill mine, fifth level, Sudbury area, Ontario. White represents greenstone; black represents ore. The width of the face represented in the drawing is 2 feet.

added that similar dikes and faults occur at the Victoria mine less than two miles distant. Here the faults are younger than the dikes.

The sulphides which form the ore bodies at Crean Hill appear to have had an origin similar to those in other deposits in the Sudbury area. They have probably been deposited from heated, mineral-bearing waters which circulated through the crushed and disturbed zone along or near the norite-greenstone contact. The presence of noticeable quantities of quartz and calcite in the ore gives confirmation to this opinion; and the fact that the greenstone is completely altered at times to a schist is additional evidence.

The Crean Hill ore is very rocky, and it is necessary to hand-pick from it 50 per cent. of rock. The hand-picked product still contains 28 to 35 per cent. of silica; it carries 2.14 per cent. of nickel and 2.91 per cent. of copper.

The Creighton Ore Body

The Creighton ore body is the largest nickel mine which is being worked in the world, and, at the same time, one of the greatest metalliferous mines of any kind. Although the Frood mine is a larger deposit, and probably has four times the quantity of ore blocked out, it is of lower grade and more rocky, and for these reasons is not being worked at the present time. Probably the great importance of the Creighton mine justifies a more detailed description than is given to other properties.

There are said to be 10,000,000 tons of ore in the mine, estimated by actual workings and diamond drill.

The mine is located at the southwest corner of Snider township, on lot 10 in the first concession, about 11 miles by wagon road west of Sudbury. A colored geological map on a scale of 200 feet to the inch accompanies the Report. The Algoma Eastern railway passes within a stone's-throw of the shafts.

Geological History

The history of the rocks and their relation to the ore body are outlined in the legend below, the older rocks being shown at the bottom of the table and the younger at the top. It may be repeated that these rocks are all of pre-Cambrian age.

Olivine diabase dikes
Trap dikes
Ore body
Granite
Norite
Greenstone

The oldest rock in the vicinity of the Creighton is what has been called greenstone. It is generally coarse-grained and looks like a gabbro or diorite; there are also fine-grained facies of the rock. The coarse-grained greenstone resembles somewhat the norite, but it appears to be more decomposed than the norite and has a greener shade, the norite having a grey tint.

The eruption of the greenstone was followed by the great norite intrusion. That the norite is younger than the greenstone is shown by the fact that it has chilled against the latter. It also holds inclusions of the greenstone, one of these larger masses being shown on the map about 1,000 feet to the north of the open pit. The character of the norite has been described elsewhere in the Report, but it may be repeated that, mineralogically and chemically, the composition of the rock is very uniform for a distance of at least 3,250 feet northwestward from the Creighton pit.

After the norite had solidified, the granite mass, which occupies parts of Graham, Waters and Snider townships, was intruded. It broke its way through the crust of the earth along the norite-greenstone contact. The age relationship of the

granite is shown in an outcrop about 800 feet north of the Creighton open pit, where the contacts are well exposed. Here the somewhat schistose norite is brecciated for about 10 feet from the contact into angular blocks from a few inches to 2 or 3 feet in diameter. These fragments of norite are cemented together by the coarse-grained granite; or, put in other words, dikes of the granite penetrate the norite through this brecciated zone. It is clear from this and other evidence that the granite is younger than the norite. The age relation is well shown at the east side of a small lake on lot 2 in the fourth concession of Snider township, where dikes of the coarse-grained granite may be traced into the norite. Hundreds of granite dikes penetrate the norite along the contact between Copper Cliff and Crean Hill mine.

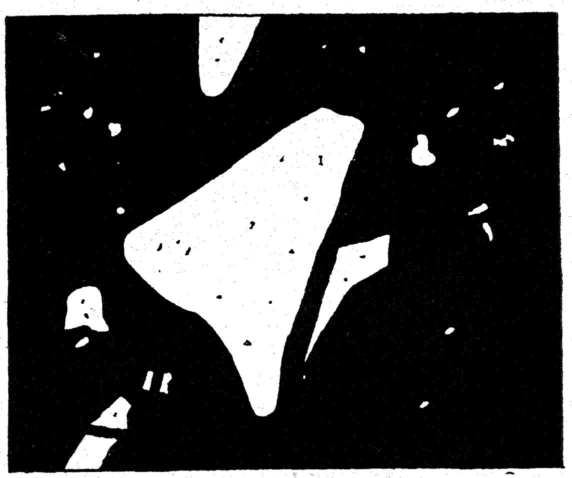

Fig. 20—Character of ore at Creighton mine, Sudbury area, Ontario, eighth level, 10 feet from hanging wall. White represents rock; black represents sulphides. Width of face 5 feet.

The next event, and the one which immediately preceded the formation of the Creighton ore body, was that which was represented by a period of tremendous crushing and brecciation along the norite-granite contact. A great crush-breccia and crush-conglomerate, of granite, greenstone and norite fragments, were formed.

A period of ore deposition closely followed the crushing and brecciation; and magmatic solutions, carrying sulphides, circulated upwards through the crushed rocks and deposited nickel, copper and iron sulphides in the spaces between the rock fragments, replacing the latter to some extent. Thus was the Creighton ore body formed.

After the formation of the ore body fissures were formed in all of the rocks in the vicinity of the deposit, including the deposit itself, and dikes of trap were intruded into greenstone, norite, granite, and the ore body. Ore deposition had practically ceased before this took place, for the trap dikes are free from ore except for small veinlets along the edges. The dikes do not cut entirely across the ore body, but appear to have penetrated it only a relatively short distance.

The final chapter in the history of this marvellous ore body was closed by the formation of another series of fissures through which were erupted coarse-grained olivine diabase dikes. These dikes cut the ore body and the trap dikes described in the previous paragraph. Their relationship to the trap dikes is beautifully shown about 1,100 feet northwest of the open pit. Here a coarse, olivine diabase dike cuts across the trap. Actual contacts are exposed which show the olivine diabase to have cooled and chilled against the trap dike. The same relationship may be seen about 3,000 feet north of the pit. The width of the trap and diabase dikes varies from about 20 to 75 feet or more. It may be added that C. H. Hitchcock, of the Canadian Copper Company, first recognized these trap dikes as distinct in age from the later olivine diabase dikes. On the map of the Creighton mine in the office of the company the diabase dikes are shown intersecting the trap dikes.

Shape and Size of Ore Body

The shape of the Creighton ore body is shown by a model, facing page 142, constructed by officials of the Canadian Copper Company. The white, horizontal lines represent the various levels, and the altitude of these levels above or below sea level are noted. Fig. B is a photograph of the model looking at the west side of the ore body; Fig. C is a photograph looking at the south end, and Fig. A looking at the north end of the ore body.

The upper part of the model was constructed from information obtained mainly from actual workings, while the lower part was outlined by means of information derived from diamond-drill cores. In July, 1916, there were but two crosscuts and no stopes in the ore body on the twelfth level. Three months later there were five crosscuts on this level and stoping had already begun. On the tenth and higher levels, however, the shape and extent of the deposit had been ascertained mostly from workings which consisted of crosscuts, drifts, and stopes.

From the model it is seen that the central part of the deposit is lenticular; that is to say, its length is much greater than its width, so that the ends "pinch" or taper out gradually. The upper and lower parts, on the other hand, are roughly oval in outline. It may be stated that its known depth is about twice its maximum length. Of course it is not possible to say how much of the deposit has been eroded during past geological ages. And it may also be noted that the depth to which the deposit goes has not yet been ascertained.

The ore body has a known depth of about 2,000 feet measured along its average dip of 45°, but the model only shows the ore body to a depth of about 1,600 feet measured along its dip. Diamond drilling ceased at about 2,000 feet, but the last drill cores still showed the presence of ore. The maximum length is about 1,000 feet. The width on the surface is about 180 feet. Between the fifth and sixth levels its width becomes abruptly less, so that on the sixth and eighth levels it has only a width of about 50 feet. Below the eighth level, however, it again becomes wider, and on the tenth it has increased to about 130 feet. Below this the diamond-drill cores show it to be even wider, in fact wider than in the great open pit on the surface.

There is a small isolated ore body, near the surface, southward from the main one. Its relative size and position are shown by the model.

More precise information than is given in the preceding paragraphs regarding the length and width of the deposit may be obtained by consulting the composite plan facing page 144. The plan shows the horizontal outlines of the ore body on the third, fourth, fifth, sixth, eighth and tenth levels. The outlines have been obtained largely from actual workings. Since the plans are horizontal sections, it is necessary to allow for the average dip of the ore body in ascertaining the actual

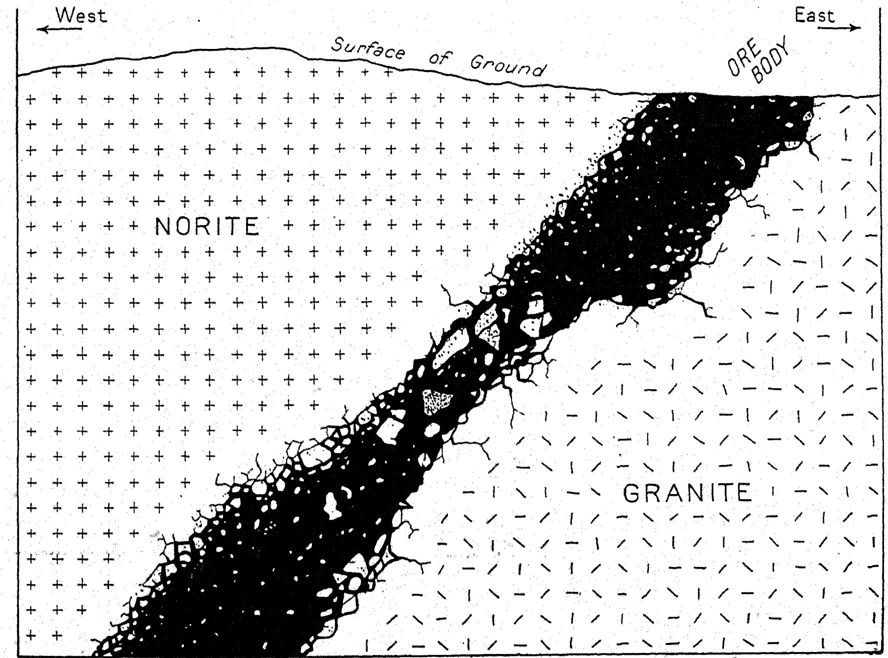

Fig. 21—Ideal cross-section through Creighton ore body, from the surface to the proposed eighteenth level, showing the nature of the deposit. Black represents ore. The norite is "spotted" with "blebs" of ore, about the size of peas, for 2,000 feet beyond the ore body. This "spotted" norite is not indicated in the drawing except along the edges. The granite is also "spotted" with ore, but to a much less extent than the norite. While the commercial ore body occurs about at the contact of the norite and granite, nevertheless the commercial ore body is found largely in the granite footwall —not in the norite.

width at any point. For instance, if the plan shows the deposit to have a horizontal width of 100 feet, then the actual width, allowing for the dip, is about 70 feet.

Nature of the Ore Body

The ore body occurs about at the contact between granite and norite, the latter forming the hanging-wall, the granite the footwall. It has been named a marginal deposit. The ore body, however, is found largely in the granite footwall, and it may be said that the limit of the commercial ore is met with when the norite hanging-wall is encountered. Sometimes, indeed, the commercial ore

ends before the norite is met with, in which case massive granite forms not only the footwall but the hanging-wall. The strike of the ore body is about north and south—really a few degrees east of north. The exact strike on the third, fourth, fifth, sixth, eighth and tenth levels may be seen by consulting the composite plan facing page 144. The dip of the ore body is about 45° to the westward, and there appears to be no change on the lowest parts of the deposit.

An examination of the stopes, crosscuts, drifts and other workings has shown that the ore body consists of a mass of rock fragments cemented together by sulphides. Diamond-drill cores from the lower part of the deposit have also demonstrated this feature. Therefore, when the model of the ore body is looked at, it must not be thought of as consisting of pure sulphides. The "rocky" nature of the ore is demonstrated by the fact that from 10 to 16 per cent. of rock is hand-picked from the ore, and there still remains from 18 to 21 per cent. of silica in this

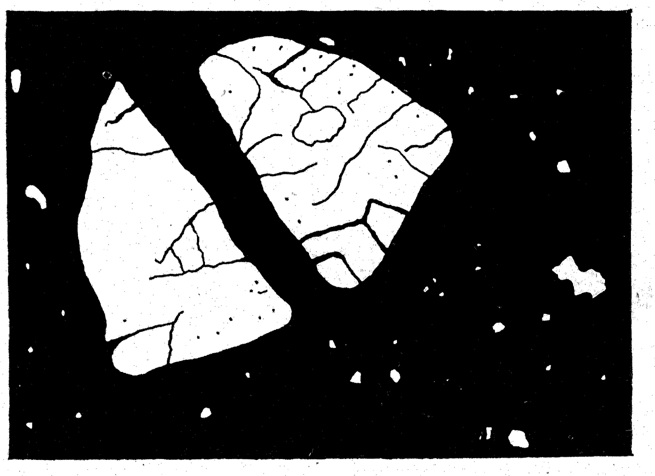

Fig. 22—Character of ore at Creighton mine, Sudbury area, Ontario, ninth level, near hanging wall. White represents greenstone boulders; black represents sulphides. Width of face 4½ feet.

hand-picked product. Of course the number of rock fragments in the deposit varies greatly in different parts of the mine. At and near the footwall and hanging-wall, and at the north and south ends the rock fragments are most numerous and, on the whole, largest. Here they may occur in such numbers as to make the ore too rocky to be of commercial value at present. Sometimes, on the eighth level, for instance, many blocks of rock of large size—5, 10, or 15 feet in diameter—occur in the centre and all parts of the ore body. However, it may be said that, generally speaking, the ore body is less rocky in the central portions than on the sides or ends.

The size of these rock fragments varies from great blocks 100 feet long down to specks which are visible only under the microscope.

The hand-picked ore contains 4.44 per cent. of nickel and 1.56 per cent. of copper.

Probably the average size of the fragments on the hanging-wall and footwall and the ends of the deposit varies from 5 or 6 inches, and less, to 2 or 3 feet. This rocky variety of ore on the hanging-wall and footwall may at times extend into the central parts of the deposit for as many as 30 feet before the fragments become smaller and less numerous, thus forming the purer or massive ore. But even in this massive type of ore it is rare to find sulphides in which tiny specks of rock do not occur.

The shape of the fragments is infinite in variety, varying from round or oval to sharply angular. Sketches showing their outlines are illustrated in Figs. 6, 20, 22 and 25.

The rock fragments consist of granite, greenstone and norite, or, where they are very small, of the various minerals which constitute these rocks, *i.e.*, feldspar,

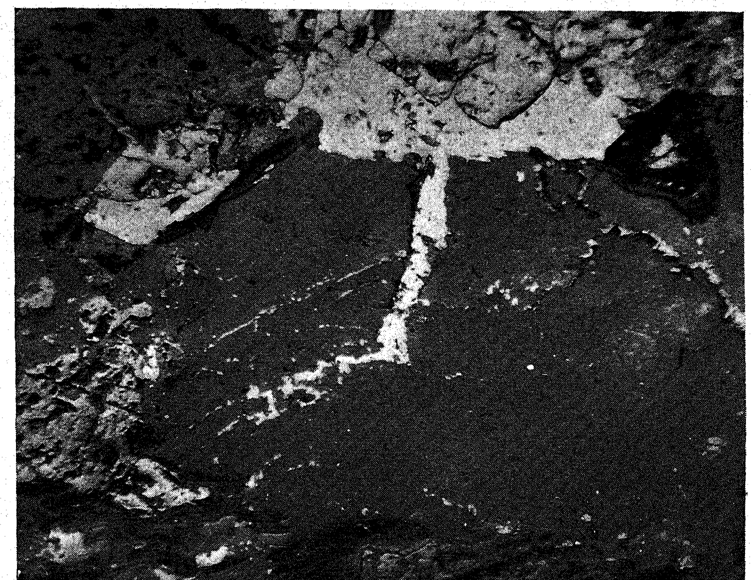

Fig. 23—Polished surface of ore, showing veinlets of sulphides (white) replacing or impregnating rock; magnified 88 diameters; Creighton mine, Sudbury area, Ontario. The sulphides replace or impregnate all the rocks at Creighton mine, whether they consist of norite, granite or greenstone. *Photomicrograph by Wm. Campbell.*

quartz, hornblende, pyroxene, and other minerals. The presence of the greenstone fragments is to be accounted for by the fact that frequently the granite footwall holds immense inclusions of greenstone. The diamond-drill cores, indeed, show that in the deeper part of the deposit the greenstone forms the footwall. The granite and greenstone fragments are most numerous, and are found in all parts of the ore body. They extend across the deposit to the norite hanging-wall. The norite fragments, on the other hand, appear to be confined largely to the proximity of the hanging-wall. Of course some of the norite fragments may have been so much altered that it may be difficult to distinguish them from the greenstone.

The contacts of many of the fragments with the sulphides are sharp and knife-like. As contrasted with this, there is frequently a transition between the frag-

ments and sulphides, as if the outer parts had been replaced and replacement had ceased before it had extended into the central parts. Sometimes, however, the replacement has continued until a particular fragment has been almost wholly replaced. Often veinlets of sulphides ramify irregularly through the fragments, and if the latter are schistose, as is frequently the case with the greenstone, the veinlets of sulphides follow along the schistose planes. Sometimes it is found, too, that "blebs" of sulphides about the size of peas occur in the fragments, whether they consist of granite, greenstone or norite. When the "blebs" occur in the norite, the latter has been called "spotted" norite.

It is common to find veins of sulphides extending from the ore body and penetrating the granite footwall and norite hanging-wall for 25 or 50 feet.

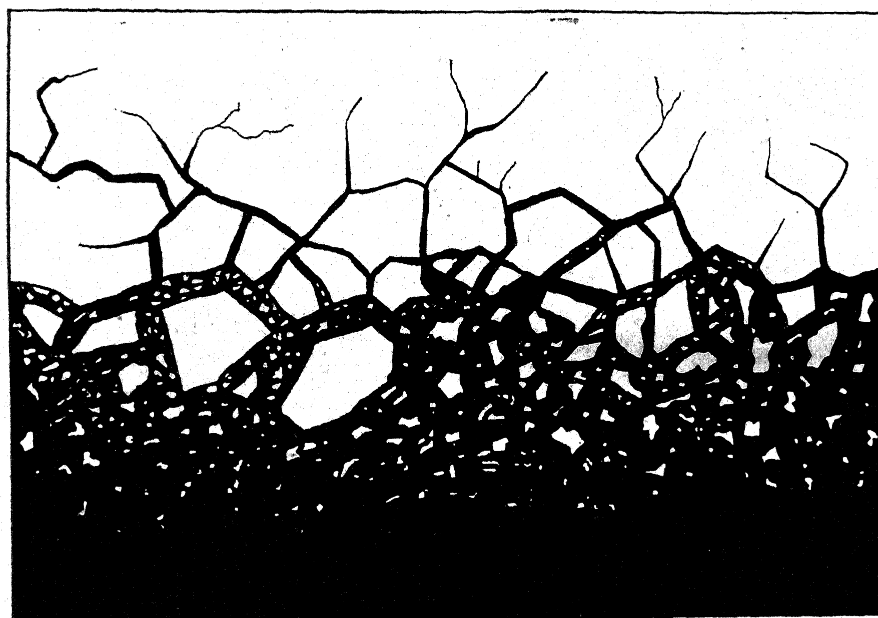

Fig. 24—"Diagrammatic drawing illustrating the character of the contact between massive sulphides (black) and norite (white)," Creighton mine, Sudbury area, Ontario. Drawing by E. Howe. The face represented in the drawing has a length of 20 feet. The drawing illustrates the fact that the ore was introduced after the norite had solidified.

Contact Between Ore Body and Norite Hanging-Wall

The character of the contact between the ore body and the norite hanging-wall has given rise to discussion. It has been stated that there is a gradual transition between the pure sulphides and the norite, but this statement does not agree with more recent observations, including those of E. Howe. The contact between the ore body and hanging-wall of norite is, comparatively speaking, abrupt. It may be three or four feet, sometimes more, sometimes less. In places it is a few inches, the commercial ore body ending abruptly against norite which is slightly impreg-

nated with sulphides. Probably the relationships have been described best by Howe in the two following paragraphs:[1]

Aside from the impressive size of the Creighton ore body, its most striking feature is the character of its contact with the norite of the hanging-wall. At a number of places in the open pit and in stopes at lower levels the change from ore to rock with no sharp line of separation is well shown. The transition may take place within a space of three or four feet, or may extend over as many yards. The character of this gradation of rock into ore calls for special consideration, as it constitutes one of the criteria upon which is based the theory of gravity segregation of the sulphides from the magma. According to most of the descriptions one expects to find the nearly pure sulphides pass by imperceptible increase in the quantity of associated silicates into a rock in which sulphides are sparingly present as accessories or altogether absent. While there is undoubtedly a gradual change from ore to rock, it would appear to be due to a mechanical mixture of sulphides and norite in the transition zone and not to a graduation in a mineralogical sense.

In all places where transition from ore to rock is supposed to exist, the norite has been extensively shattered in the neighbourhood of the ore, and the sulphides appear to have penetrated the norite along the cracks and fissures so formed, while angular fragments of

Fig. 25—Shows relation of sulphides to norite hanging wall. White represents norite; black represents sulphides. Eighth level, Creighton mine, Sudbury area, Ontario. Width of face 15 inches. The drawing illustrates the fact that the sulphides were introduced after the norite had solidified.

norite are included in the sulphides close to the rock, Fig. 24. The veinlets of sulphides die out gradually in the norite away from the massive ore, while the rock fragments included in the sulphides become less numerous and smaller in size as their distance from the hanging-wall increases. There is thus a transition from ore to rock in a mechanical sense, and, from a mining standpoint, the expression is justifiable. Neither megascopically nor with the aid of the microscope could the writer recognize a petrographical graduation.

Generally the norite for several feet from the contact of ore body or granite becomes finer in grain. The explanation of this appears to be that it originally chilled against the greenstone. At a later time the granite was intruded at the contact between the greenstone and norite.

Contact Between Ore Body and Granite Footwall

The contact between the granite footwall and the ore body is much the same as that between the ore body and the norite. There is, however, a slight preponderance of chalcopyrite in the ore body at its contact with the granite. The contact is more irregular along the granite footwall than along the norite

[1] Economic Geology, Vol. IX, September, 1914, p. 514.

hanging-wall. To illustrate this, crosscuts Nos. 9 and 10 on the twelfth level may be cited. The contact of the ore body and massive, barren granite in No. 9 crosscut is sharp, comparatively speaking, the transitional material having a width of only two feet. On the other hand, in No. 10, the adjacent crosscut to the north, the transitional material has a width of about 50 feet or more. Here veins of sulphides 6 to 15 inches in width are found intersecting the granite. They increase in size until blocks of granite several feet in diameter are enclosed in sulphides. The granite blocks become smaller and smaller as the ore body is approached, until, finally, more massive ore is found.

Mineralization of Hanging-Wall and Footwall

The hanging-wall is mineralized for a distance of about 2,000 feet to the west of the ore body. This mineralized area extends in a northeastward and southwestward direction for about three-quarters of a mile. The general outlines of this "gossan," as it is called, are shown on the large scale map of the Creighton mine which accompanies this Report. Considerable drift covers the gossan, and it is difficult to obtain the outlines accurately, so that the boundaries as shown are to be considered approximate.

The mineralization is most intense near the ore body, and its intensity decreases irregularly as the distance from the ore body increases. Some of the mineralized norite near the deposit contains from 1½ to 2½ per cent. of nickel and copper combined, but it does not at the present time constitute commercial ore.

Part of the mineralized norite is fresh-looking, and it has been stated by Coleman and Barlow that undecomposed hypersthene is found closely associated with the sulphides. However, it is equally true that much, it is difficult to say what per cent., of the mineralized norite is slightly sheared or brecciated and altered. It often contains great numbers of angular and round inclusions of other rocks, including greenstones. It would seem that there has been enough shearing and brecciation to have allowed sulphide-bearing solutions to circulate through and penetrate the rock, thus accounting for its mineralization.

The trap and olivine diabase dikes, described elsewhere, cut sharply across the mineralized norite and ore body, showing that the period of ore deposition took place before the dikes were intruded. They are practically barren of sulphides. In places the trap dikes have chilled against certain well-defined shear zones in the norite, proving, further, that some of the shearing of the norite took place before the dikes were intruded.

The mineralization of the granite footwall is much less intense than that of the hanging-wall. It extends into the granite a maximum distance of about 100 feet, but for the most part it is much less, probably 25 or 50 feet. During the process of impregnation the sulphides sometimes formed "blebs" about the size of peas in the granite, resulting in what may be called "spotted" granite, Fig. 26, which is analogous to the "spotted" norite of certain writers. The remarkable point about the granite, which has been partly replaced or impregnated by sulphides, is the freshness of the minerals which constitute it. The feldspar retains its pink colour and bright, shining, cleavage faces. Evidently the solutions did not decompose the granite to any appreciable degree.

Faults

In many parts of the mine, particularly between the sixth and tenth levels, a fault or slip has been encountered. It has not been proved to be continuous, and occurs about at the contact of the ore body and the norite hanging-wall. Frequently mining operations are carried to the fault, but rarely beyond, so that the fault often constitutes the limit to which the commercial ore body may be mined. It has not been ascertained if any great movement has taken place along this fault, which is two or three inches wide, or more, and often has clay-like material in it. The rocks on each side have sometimes been rendered schistose. The fault was evidently formed after the ore body, but a little deposition of ore has taken place after the fault was formed, for some sulphides occur in it, and frag-

Fig. 26—"Spotted" granite, actual size. Black represents sulphides; white represents granite. The sulphides replace or impregnate the rock. Creighton mine, Sudbury area, Ontario.

ments of the schistose rock from the sides of the fault have been found cemented together by sulphides.

Less frequently a somewhat similar fault is found in the footwall, between the granite and ore body. Other faults occur elsewhere in the mine.

Dikes Intersecting Ore Body

There are two series of basic dikes which intersect the ore body. The older set is the trap dikes referred to elsewhere. The map of the Creighton mine shows one of these dikes at the northwest side of the open pit. On the third level of the open pit what is probably this same trap is found on the hanging-wall at the northwest end of the pit. The workings show that it extends down to about the

sixth level. A similar trap has been observed on the tenth level and at other parts of the mine. These dikes are barren of ore, though sometimes they have been slightly brecciated, thus allowing stringers of sulphides a few inches in width to ramify through them, particularly along their edges. The deposition of these sulphides along the edges of the dikes must have taken place long after the formation of the ore body. The traps are intersected by numerous jointing planes which are often slickensided. The presence of the joints sometimes causes trouble in mining operations when the dikes are met with, the rock having a tendency to fall. The dikes consist essentially of plagioclase and hornblende, with an ophitic texture. They are properly named uralitic diabase, but have been called trap in this Report in order to avoid confusing them with the olivine diabase dikes.

The younger series of dikes is the olivine diabase. One of these occurs on the surface at the northwest end of the open pit, and it may be traced to the southeast across the ore body. It is well exposed on the first level of the open pit, where its fine-grained, chilled edges are seen in actual contact with the sulphides. Before reaching the granite footwall it breaks up into four or more smaller dikes. Even in the case of these diabase intrusions there has been a small amount of mineralization after they solidified, for small veinlets of sulphides cut them at and near the edges. The formation of the ore body and the mineralization of the hanging-wall and footwall were practically completed before the intrusion of the trap and diabase dikes.

An analysis of the trap dike is given in the table below.

Table showing Chemical Composition of Trap Dike in the Open Pit, at Creighton Mine, on the Hanging-Wall of the Third Level at the North End.

SiO_2	52.54
Al_2O_3	16.10
Fe_2O_3	5.88
FeO	9.94
CaO	7.35
MgO	1.66
Na_2O	3.02
K_2O	1.58
H_2O	1.84
CO_2	Trace
Total	99.91

Origin of the Ore Body

From what has been said in preceding paragraphs it is evident that the formation of the Creighton ore body was preceded by a period of tremendous brecciation and crushing along the contact of granite and norite. That this crushing took place largely in the footwall is shown by the fact that most of the rock fragments in the ore consist of granite and greenstone, while the norite fragments are confined mostly to the vicinity of the hanging-wall. In other words, the commercial ore body occurs in the granite footwall—not in the norite. Sometimes indeed the granite actually forms the hanging-wall as well as the footwall. Generally speaking, it may be stated that, when the norite hanging-wall is met with, the commercial ore comes more or less abruptly to an end.

In searching for an explanation of the origin of the Creighton ore body an observer is soon confronted with the fact that the gravity segregation theory does not appear to be a suitable one. That theory supposes that while the norite was still molten the sulphides settled to the bottom of the norite, largely by means of gravity, and rested on the granite footwall. Now it has been shown elsewhere that the granite footwall is younger than the norite hanging-wall. Thus it is clear that the sulphides could not have settled on the granite, since the latter rock was not intruded until the norite solidified. While the Creighton ore body is not referred to, nevertheless this objection to magmatic segregation was pointed out many years ago by Frank D. Adams,[1] and later by L. P. Silver.[2]

A second point which presents an obstacle to a belief in gravity segregation is found in the character of the norite hanging-wall. The norite at its contact with the ore body is brecciated into fragments for a distance of from 3 to 12 feet or more, Figs. 21, 24. The sulphides cement these blocks and fragments together. It is evident, therefore, that the sulphides were introduced after the norite had solidified. This being so, it is apparent that gravity segregation cannot be accepted as an explanation of the origin of the ore.

It would seem that it is necessary to fall back on the time-honoured theory of deposition from heated solutions. This theory requires little explanation. The crushed nature of the granite footwall and of part of the norite hanging-wall presented an ideal zone for the circulation of heated aqueous solutions. These solutions possibly carried little else than sulphides. It is supposed that they came from great depths, and nearer the surface the sulphides were precipitated, filling the spaces between the fragments in the crush-breccia and crush-conglomerate. As might be expected, the hanging-wall and footwall and the fragments composing the crush-breccias and crush-conglomerates are more or less replaced or impregnated by sulphides. Since the ore body dips at an angle of 45°, it is obvious that the solutions in rising along the contact would also tend to rise vertically and penetrate into all the cracks and crevices of the norite hanging-wall. This appears to be exactly what took place, for the norite is impregnated or replaced by sulphides for as much as 2,000 feet or more from the granite. The impregnation is naturally greatest near the contact, and it becomes gradually less as the distance from the contact increases. It may be added that, under present economic conditions, there appears to be little commercial ore in the norite. The granite footwall is mineralized only for a maximum distance of about 100 feet beyond the ore body.

An examination of the mineralized portion of the norite for 1,000 feet from the ore body shows that a minor amount of crushing, shearing and brecciation has taken place. This was accompanied by some alteration of the rock. At the same time it is true that much of the norite in this mineralized zone is perfectly fresh, even when heavily impregnated with sulphides. It is also true that the granite where it has been replaced by sulphides remains fresh, the feldspars retaining their colour and lustre. The immense stopes of the Creighton mine demonstrate that there are all gradations between granite slightly replaced or impregnated with

[1] Jour. Gen. Min. Ass. Province Quebec, 1894-95, p. 49.

[2] Jour. Can. Min. Inst., Vol. 5, 1902, pp. 536-542.

sulphides and granite which is almost wholly replaced. In the latter case the remaining specks of feldspar still retain their fresh appearance.

It is evident, even to those who favor magmatic segregation as an explanation of the origin of the deposit, that some of the sulphides were deposited from hot waters. The sulphides, for instance, which occur along the brecciated edges of the trap and diabase dikes were unquestionably deposited from hot waters long after the norite solidified. There appear to be no special characteristics which distinguish these sulphides in the trap or diabase dikes from the sulphides in the ore body.

It may be added, in connection with the origin of the ore body, that the suggestion has been made by E. Howe[1] that the sulphides were injected in a molten state as a later intrusive after the norite had solidified. The writer is in entire agreement with Howe's statement that the sulphides came in after the norite had solidified, but whether they were introduced in a molten condition or by means of hot magmatic waters may be a debatable question.

No. 2 Ore Body, Canadian Copper Company

The mine belonging to the Canadian Copper Company, known as No. 2, is on the northern outskirts of the town of Copper Cliff.

The deposit occurs in a dike of diorite or gabbro, which is considered by some writers to be connected with the norite about a mile to the north. The dike, which is from 100 to 180 feet in width, intersects coarse-grained granite and greenstone. The youngest rocks in the vicinity of the mine are diabase dikes which cut all the rocks mentioned.

The shape and size of the ore body on the various levels are shown on the composite plan, Fig. 29.

The character of the ore body does not differ from that of other deposits in the area. The ore consists of fragments of the diorite dike cemented together by sulphides; and of stringers and irregular masses of sulphides which replace or impregnate the dike. Much of the diorite is "spotted" with blebs of ore. The mineralization appears to be confined wholly to the dike. The fact that fragments of the diorite dike are enclosed in the sulphides shows that the sulphides were introduced after the dike had solidified.

A fault intersects the dike of diorite in which the ore body occurs. The plane of this fault dips about 48° to the northwest, Fig. 27. The horizontal displacement, or throw, has been proved by workings to be about 350 feet, but the vertical movement has not been ascertained. The fault completely cut off the ore body, and although the dike itself, spotted with ore, has been found 350 feet to the southwest, Fig 28, the commercial ore body has not yet been located, in spite of a vigorous campaign of diamond drilling. It has not been determined whether the fault is normal or reversed. If it is normal in character and the throw is great, thousands of feet, it may be that No. 2 mine is simply the faulted-down portion of Copper Cliff mine, which is about half a mile to the south. If the throw is

[1] Economic Geology, September, 1914.

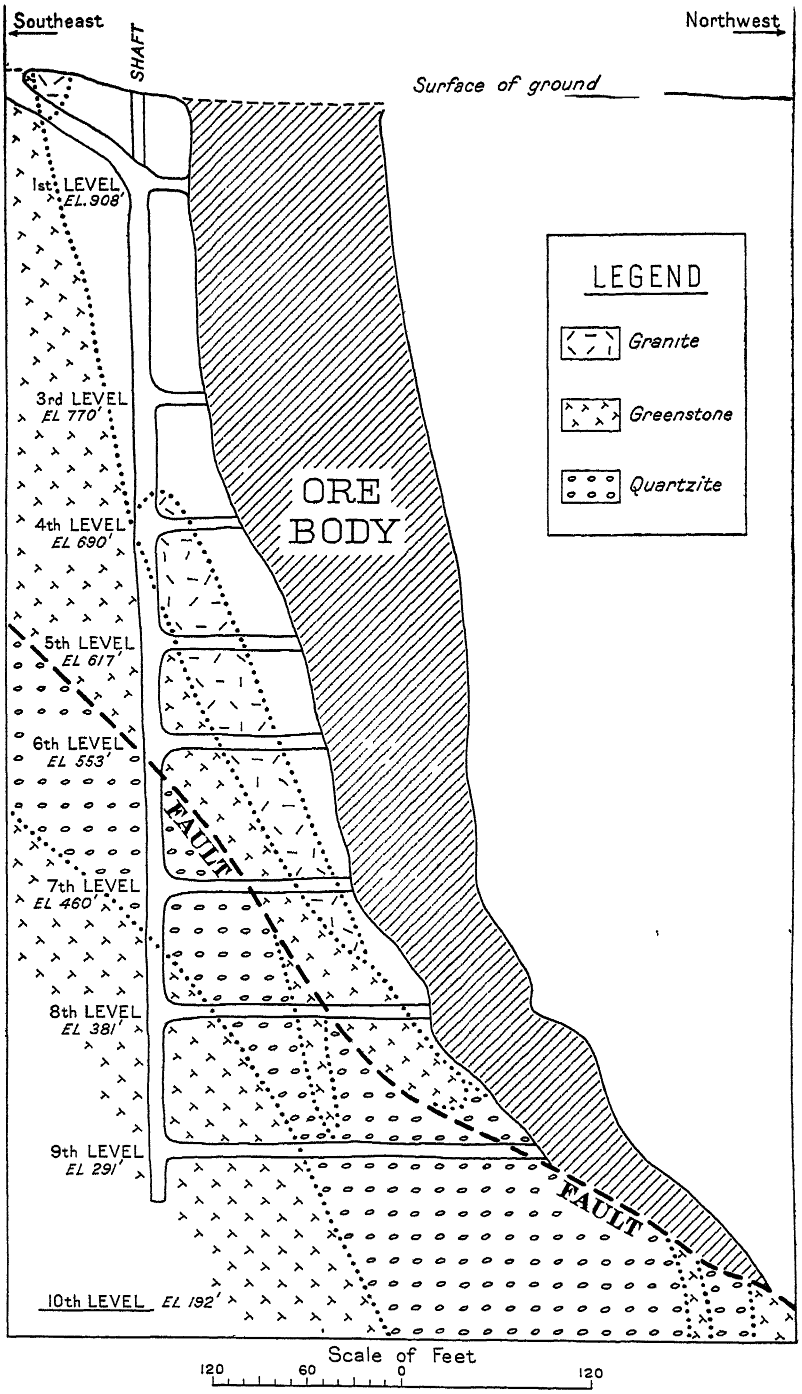

Fig. 27—Cross-section through No. 2 ore body, Canadian Copper Company, Copper Cliff, Ontario. The section shows the position of the fault which has cut off the ore body. Cross-section by Canadian Copper Company.

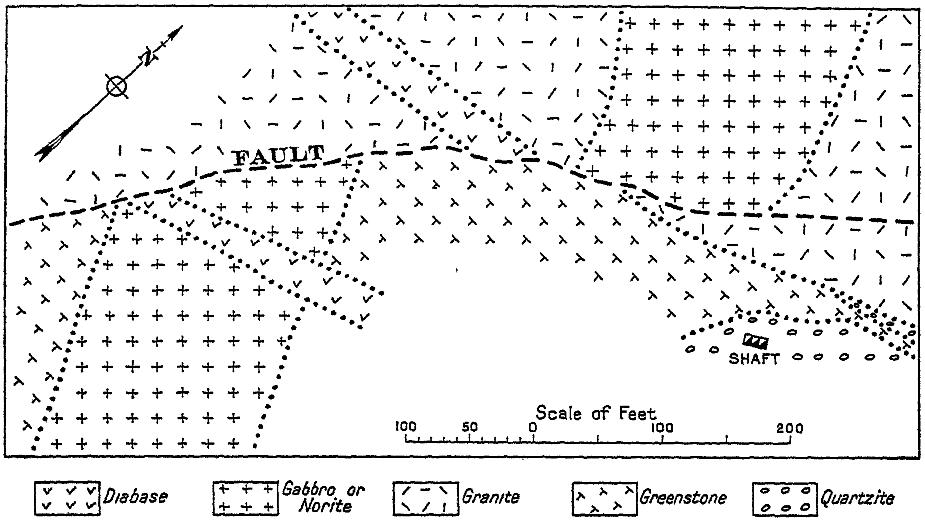

Fig. 28—Plan of ninth level, No. 2 mine, Canadian Copper Company, Copper Cliff, Ontario, showing fault. The dike has been faulted 350 feet to the southwest, but the vertical displacement is not known. From plans of the Canadian Copper Company.

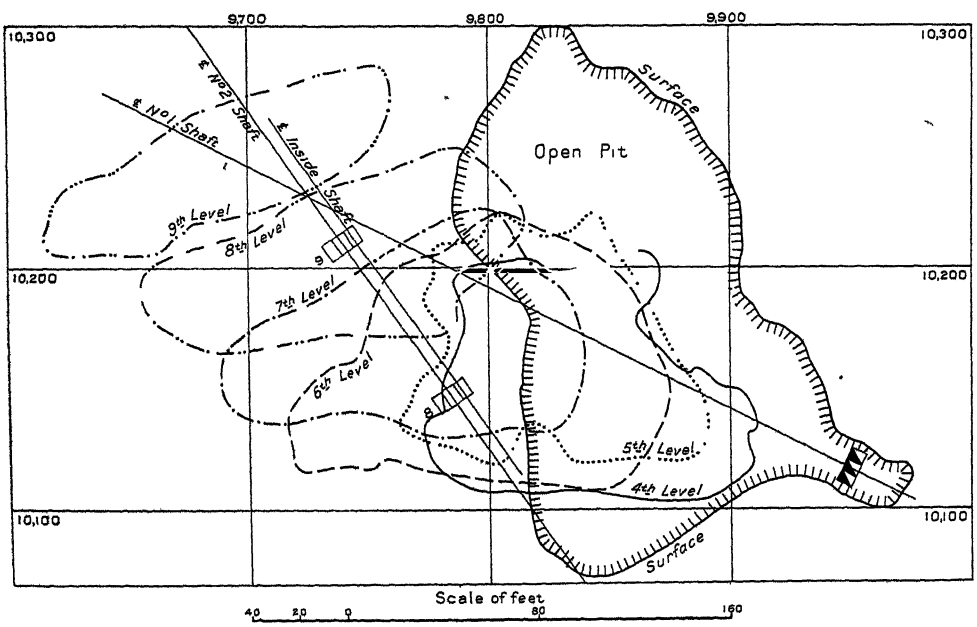

Fig. 29—Composite plan showing outlines of ore body on the surface, and the fourth, fifth, sixth, seventh, eighth and ninth levels, No. 2 mine, Canadian Copper Company, Copper Cliff, Ontario. The left side of the drawing is west, the right side is east. From plans of the Canadian Copper Company.

less than this and also normal, it may be that the lost ore body occurs below the drift at some point between Copper Cliff mine and No. 2 mine, in which case it might be advisable to run an exploration drift, following the dike, from the underground workings of Copper Cliff mine to No. 2 mine.

Very little ore was being broken in the fall of 1916, but ore was still being raised from the stopes. Unless the continuation of the ore body on the other side of the fault can be located, the main ore body of the mine is worked out. It has been one of the important mines of the area.

There is ore along the dike to the northward of No. 2 mine as far as Lady Macdonald Lake, a few pits having been opened here and there.

The Vermilion Ore Body

The Vermilion was the smallest deposit in the area which was being worked in the year 1916. It is of value on account of the presence of the precious metals, gold, silver, platinum and palladium. Were it not for these metals it would not pay to operate the property for the nickel and copper contents alone. The mine is situated on lot 6 in the fourth concession of Denison township, about a mile south of Crean Hill.

The deposit consists of a number of small veins or irregular bodies of ore from a few inches to about 15 feet in diameter. The largest ore shoot yet encountered is only 38 feet long by about 15 feet wide. These ore bodies occur in an irregular fashion in the rocks, making it difficult to discover new ones. The ore is found in greenstone, quartzite and norite. It is evident that the rocks were fractured and that the ore was introduced into the irregular fissures and cracks so produced. Ore shoots have been found to a depth of 115 feet, but exploration work has been carried to about 150 feet in depth.

The deposit contains an unusual number of minerals, including pyrrhotite, chalcopyrite, bornite, chalcocite, native copper, cassiterite, native gold, sperrylite, millerite, polydymite, and quartz.

It is generally agreed by all observers that the ore was introduced by hot water, circulating through the cracks and irregular fissures in the rocks.

Aside from its interest as a producer of precious and rare metals, the Vermilion is noteworthy on account of the fact that the mineral sperrylite, $PtAs_2$, was discovered at the property. Sperrylite was afterwards shown by G. R. Mickle[1] to occur mostly in chalcopyrite. It was found by F. L. Sperry, after whom it was named. Sperry forwarded the material to Messrs. Wells and Penfield, who made the determination.

The Garson Ore Body

The Garson ore body is located about 10 miles northeast of Sudbury, on lots 4 and 5 in the third concession of the township of Garson. It is connected with the main line of the Canadian Northern railway between Toronto and Winnipeg by a branch line.

[1] A. P. Coleman, Ont. Bur. Mines, 1905, Vol. XIV, Part III, p. 161.
The Nickel Industry, 1913, p. 29, A. P. Coleman.

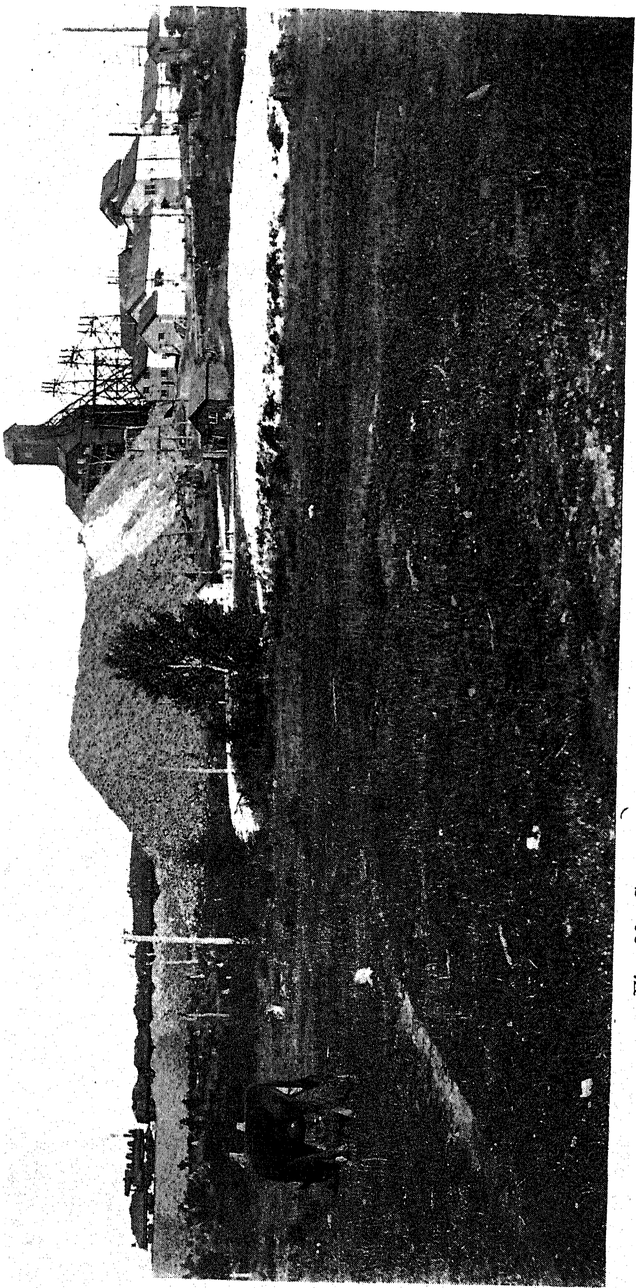

Fig. 30—Garson mine, Sudbury area, Ontario, September 9th, 1916.

The mine occurs on a hill at the north edge of a great sand and gravel plain; these deposits of sand and gravel have covered much of the contact between the norite and adjacent rocks and also much of the ore bodies, Fig. 31. The drift and the schistose and mineralized character of the rocks have obscured the age relationships of the formations. Judging, however, from general geological conditions elsewhere in the Sudbury area, the oldest rocks at the Garson mine appear to be schistose quartzites and greywackés of the Timiskaming series. Probably the rock next in age is greenstone. The latter is generally fine-grained, somewhat schistose at times, consisting almost altogether of dark green minerals,

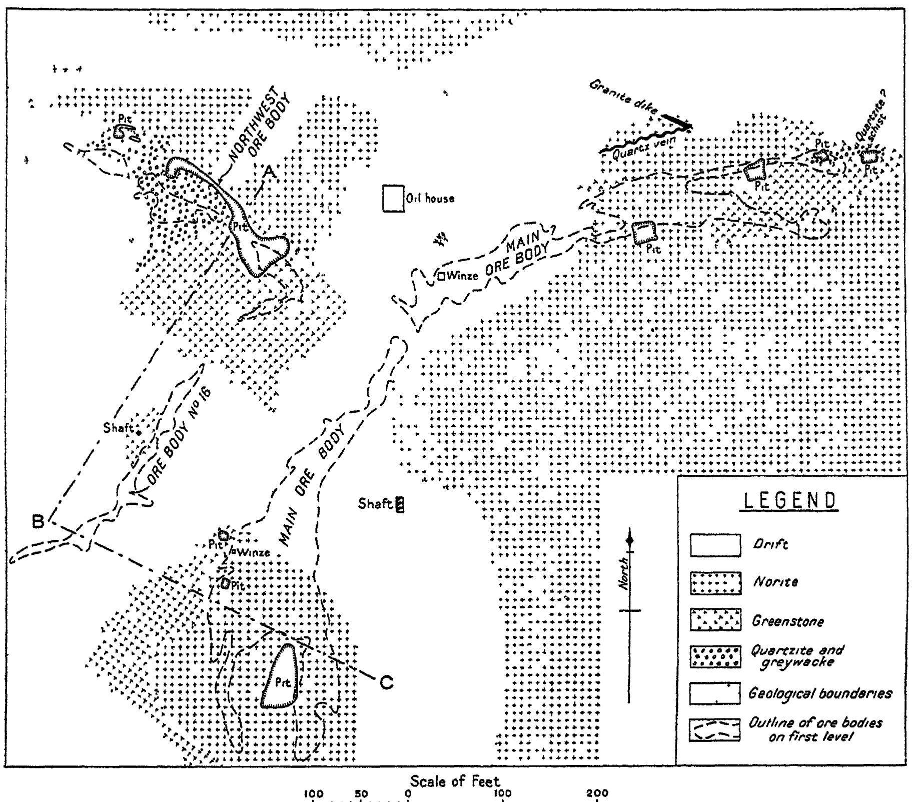

Fig. 31—Geological map of Garson mine, showing outline of ore bodies on first level, and location of cross-section A B C, Sudbury area, Ontario.

hornblende, etc. Pillow structure and amygdaloidal textures were noted in the greenstone in one instance about a mile to the east of the mine, but these appear to be rare. Following the greenstone the great norite intrusion then broke into the crust of the earth. This rock in the vicinity of the mine for 200 or 300 feet from the contact has been partly altered by shearing and other stresses to a schist or gneiss, and is much decomposed, resembling in these respects the norite at Victoria mine. It is intersected by dikes of medium-grained granite as wide as 30 feet, which contain only small amounts of coloured minerals, *i.e.*, mica or

hornblende. The relation of these dikes, which are probably aplites, to the ore body has not been observed. After the shearing of the norite and adjacent rocks took place the ore body was formed. This is evident from the fact that fragments of the schistose norite are found embedded in the sulphides, and stringers of sulphides often cut across the schistose planes of the norite. Finally, all the rocks previously mentioned, and the ore body as well, are cut by fresh diabase dikes which resemble in texture and freshness the olivine diabase dikes which are of common occurrence elsewhere in the area. One of these dikes, having a width of 17 feet, cuts the ore body on the sixth level, and another is found on the surface about a quarter of a mile northeast of the shaft. A stringer from the latter dike intersects one of the granite dikes referred to above.

The Garson ore body is probably the most complex, in respect of its form, of any of the deposits which were being worked in the summer of 1916. It has been referred to by other writers as a faulted marginal deposit. Mining has been carried on to a depth of 600 feet vertically, but exploration by diamond drill has demonstrated that the deposit continues to at least a depth of 1,800 feet measured along the dip of the main ore body.

The occurrence really consists of three ore bodies; *i.e.,* (1) the main ore body, (2) the northwest ore body, and (3), No. 16. The outlines of these ore bodies on the first, second, third, fourth and sixth levels are shown by the composite plan, facing page 158.

The main ore body has a general northeast-southwest strike and a dip of 53 to 60 degrees to the southeast. It will be seen from the composite plan that it is lenticular in shape, and forms, roughly speaking, an arc of a circle, the northeast part bending easterly, and the southwest part bending southerly. Of the marginal deposits, *i.e.,* those which occur at or near the contact of norite and adjacent rocks, the main ore body at the Garson is unusual in respect of its dip to the southeastward, most of the other marginal deposits along the southern range dipping vertically or to the northwestward. The main ore body has a length of about 1,000 feet, or more, and, in places, a width of 100 feet, or more. It has been mined to the sixth level, about 600 feet vertically, but diamond-drill cores show that it extends to at least 1,800 feet in depth measured along its dip.

The northwest ore body, as its name implies, strikes to the northwest. It has a steep dip of 80° or 90° to the southwest. The deposit consists of three lenses which pitch towards the southeast. Little mining has been done on the northwest ore body below the fourth level.

The ore body, known on the surface as No. 16, is a narrow vein-like deposit which strikes to the southwest and dips at about the same angle as the main ore body; *i.e.,* 53° to 60° to the southeast.

The three ore bodies have probably been formed along lines of fissuring, the fissuring having been accompanied by shearing and brecciation. The shearing has often been so intense that the wall rocks have been altered to schists, making it difficult to determine what kind of rocks these schists were originally, whether norite, greenstone or greywacké. The schistose character of the wall rocks is in strong contrast to the wall rocks of such ore bodies as Creighton, Murray, Worthington, etc., where the rocks usually retain their massive character.

The main ore body occurs near the contact of norite and adjacent rocks, the latter consisting of greenstone, greywacké or quartzite. The ore appears to occur for the most part in the adjacent rocks, although some is found in the norite. However, the schistose character of the wall rocks, including norite, makes it difficult to always ascertain whether the ore bodies do occur in the norite or the other mentioned rocks. The problem is sometimes complicated also by the occurrence in the norite of great numbers of quartzite or other inclusions, as may be seen on the surface at the southwest end of the main ore body. When the norite with these inclusions has been rendered schistose, the difficulty of ascertaining the character of the rock, particularly below the surface, is readily appreciated. On the sixth level, however, the ore body appears to occur mainly in schistose greywacké and quartzite.

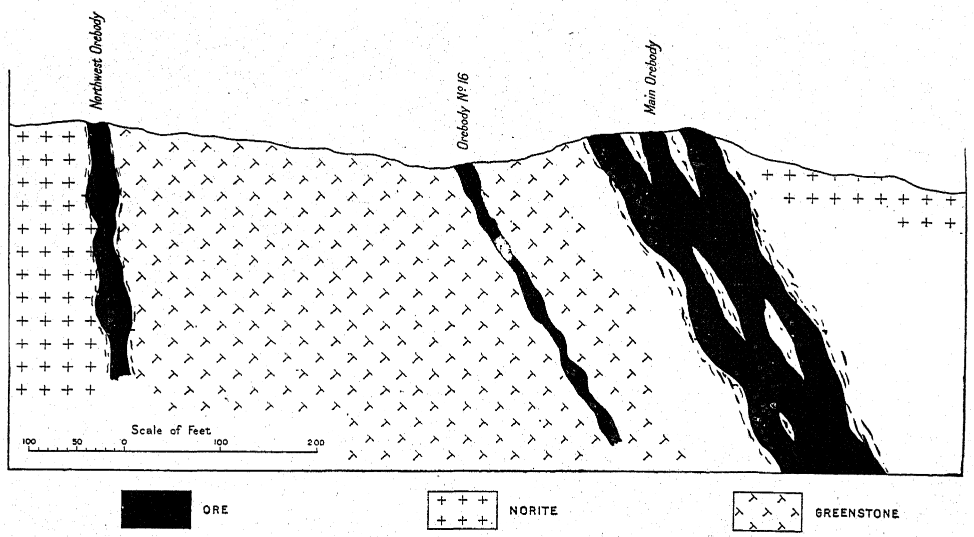

Fig. 32—Diagrammatic drawing along line A B C, see Fig 31, showing ore bodies at Garson mine and their relation to the norite and greenstone.

At the northeast end of the main ore body the rocks on the surface are massive and non-schistose, their character and relation to the ore being shown in a pit and winze near the northeast end. The sulphides here are found along the brecciated contact of greenstone and norite, angular fragments of both rocks being cemented together by the sulphides, while veinlets of ore penetrate into cracks in the norite and greenstone.

Although the relation of the main ore body to the wall rocks may not always be clear, for the reasons given above, the relation of the northwest ore body, on the other hand, to the wall rocks seems quite clear. The northwest ore body occurs at the contact of the norite and greenstone or greywacké, mainly the greenstone. The ore body, while following the contact, occurs nevertheless almost wholly in the greenstone, Figs. 31 and 32.

The relation of the third ore body, that one known as No. 16, is also simple. It occurs wholly in the greenstone, and is undoubtedly a fissure vein in which the wall rocks are impregnated or replaced with sulphides.

A diagrammatic cross-section through the three ore bodies is shown in Fig. 32, and it illustrates the relation of the ore bodies to the enclosing rocks.

The walls of the ore bodies are for the most part commercial, that is to say, mining ceases when the amount of sulphides in the rocks becomes too small to pay. Rarely are sharp contacts between the sulphides and wall rocks found. Mineralization has followed along the fissures and brecciated zones and has penetrated every crack and crevice. The ore bodies, like the other deposits in the Sudbury area, contain great numbers of fragments of the adjacent rocks: norite, greenstone,

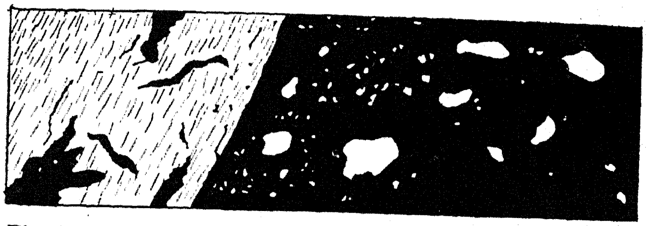

Fig. 33—Diagrammatic sketch showing ore body and schistose rock on hanging-wall, Garson mine, Sudbury area, Ontario, sixth level. Black represents sulphides. Width of face 12 feet.

greywacké and quartzite, or their schistose equivalents. The rocky nature of the ore is shown by the fact that 25 per cent. of rock is hand-picked from the ore, and this hand-picked product still contains about 24 per cent. of silica. Like other ore bodies the large stopes often contain great masses of rock, too low-grade to work, surrounded by richer material. The ore contains 2.4 per cent. of nickel and 1.7 per cent. of copper.

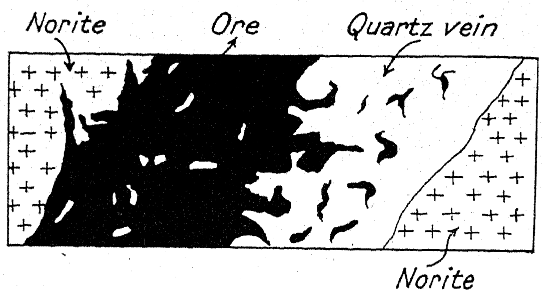

Fig. 34—Diagrammatic sketch showing quartz vein on foot-wall of main ore body, Garson mine, Sudbury area, Ontario. The width of the cross-section represented in the sketch is 20 feet.

The Garson ore bodies are replacement or impregnation deposits formed along fissured, brecciated and sheared zones. The sulphides are found impregnating or replacing the rocks, whether they consist of norite, greenstone, greywacké or quartzite. They occur in almost pure masses, or in irregular veinlets, or in disseminated grains. That they were introduced after the norite had solidified and even after it was rendered schistose, is proven by the fact that blocks of the massive and schistose norite are cemented together by the sulphides. Where the norite is schistose, veinlets often cut across the schistose planes.

A marked feature in the main ore body is the unusual amount of quartz associated with the sulphides. Between the surface and the fourth level the quartz occurs in the form of a vein cutting the norite; the vein constitutes the footwall of the ore body for a few hundred feet in length and down to the fourth level. This quartz vein averages about 6 feet in width, but the width is variable, being from a few feet to 12 or 14 feet. The contact between it and the sulphides is not a sharp one, Fig. 34, the sulphides ramifying into the quartz in veinlets as if they had been deposited a little later than the quartz. This assumption is strengthened by the presence of well rounded fragments of quartz embedded in the sulphides. About 35,000 tons of the quartz have been mined, demonstrating the large amount of the material which is present. There still remain in the mine many thousand tons. Apart from this quartz vein on the footwall of the main ore body, the ore bodies contain an unusual amount of quartz, so closely intermingled with the sulphides that it is impossible to escape the conclusion that the two were deposited during the same period of mineralization. In addition to the quartz there is a lesser amount of calcite, also closely intermingled with the ore, Fig. 35.

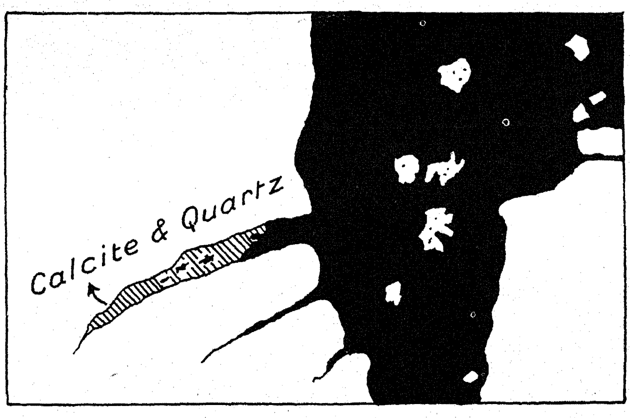

Fig. 35—Veinlet of calcite and quartz containing also sulphides, Garson mine, sixth level, Sudbury area, Ontario. Cross-hatched area represents calcite and quartz, with some sulphides; black represents sulphides; white represents rock. Width of face 12 inches. The calcite, quartz and sulphides appear to have been deposited during the same period of mineralization.

Veinlets, an inch or so wide, of calcite and galena, occasionally intersect the ore bodies.

A well-defined fault occurs on the sixth level 190 feet southeast of the shaft. It strikes north and south and dips at an angle of about 30° to the east. The extent of the movement along the fault has not been ascertained, but it does not appear to have disturbed the ore body to any appreciable degree. Along the fault the rocks and ore body have been crushed and the rocks altered in part to clay-like material. Slickensided surfaces are common. This fault appears to have formed long after the deposition of the ore bodies. It is similar in character to the well-defined faults at Crean Hill and elsewhere.

Fig. 36—Sixth level, Garson mine, Sudbury area, Ontario, showing manner in which the sulphides replace the schistose rocks. Width of face 3 feet. Black represents sulphides; white, rock.

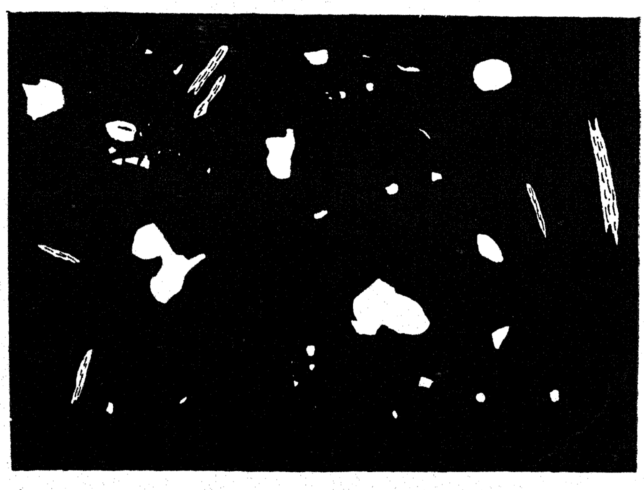

Fig. 37—Character of ore at Garson mine, Sudbury area, Ontario, sixth level. White represents rock fragments, some of which are schists; black represents sulphides. Width of face 5 feet.

The origin of the Garson ore bodies seems reasonably clear. The schistose and altered character of the wall rocks, their replaced and impregnated condition, the presence of large amounts of quartz, and to a less degree of calcite, and the vein-like nature of some of the ore bodies appear to indicate that the deposit was formed by deposition of the sulphides, the quartz and the calcite from hot circulating waters.

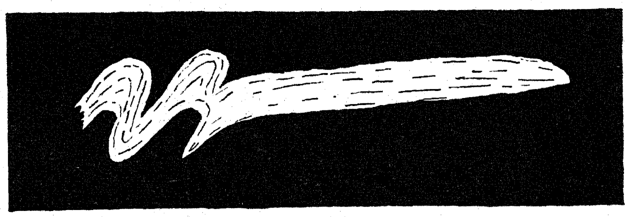

Fig. 38—Fragment of schist in sulphides, sixth level, Garson mine, Sudbury area, Ontario. The majority of rock fragments in the ore at Garson mine are schists or schistose rocks. Width of face 15 inches.

The Levack Ore Body

The Levack mine is situated on lots 6 and 7 in the second concession of Levack township. It is about four miles to the northeast of Levack station, which is on the main line of the Canadian Pacific railway. A branch line of the railway has been built to the mine.

The geology of the deposit appears to be comparatively simple, the rocks in the vicinity consisting chiefly of granite-gneiss and the norite-micropegmatite.

The granite-gneiss contains many fine to medium-grained greenstone inclusions. Sometimes these are drawn out into long schistose or gneissoid lenses, in which veinlets of granite have been injected parallel to the schistose or gneissoid planes. This has produced a banded gneiss. At other times the greenstone inclusions are brecciated into round or angular fragments, and the granitic magma has been injected into the spaces between the fragments. These basic greenstones, which now constitute a part of the granite-gneiss complex, appear to have been described as sudburite by C. Brackenbury.[1] Cutting this complex there are several fine-grained basic dikes near the mine. These have not been seen in contact with the ore body or the norite, so that their age relation to the deposit and to the norite was not ascertained. The norite at its contact with the gneiss strikes to the northeastward; and the workings and the diamond-drill cores show that the contact dips to the southeast at an average angle of 45°. The contact between granite-gneiss and norite is not exposed in the vicinity of the mine. About 4 miles to the northeast, however, at the Big Levack, a good contact is met with, and it is seen that the norite is younger than the granite-gneiss. The norite comes sharply against the granite-gneiss, there being no transition zone between the two rocks.

[1] Ont. Bur. Mines, Vol. 23, Part I, pp. 194-201. An excellent petrographic description of the rocks at Levack mine is given by Mr. Brackenbury.

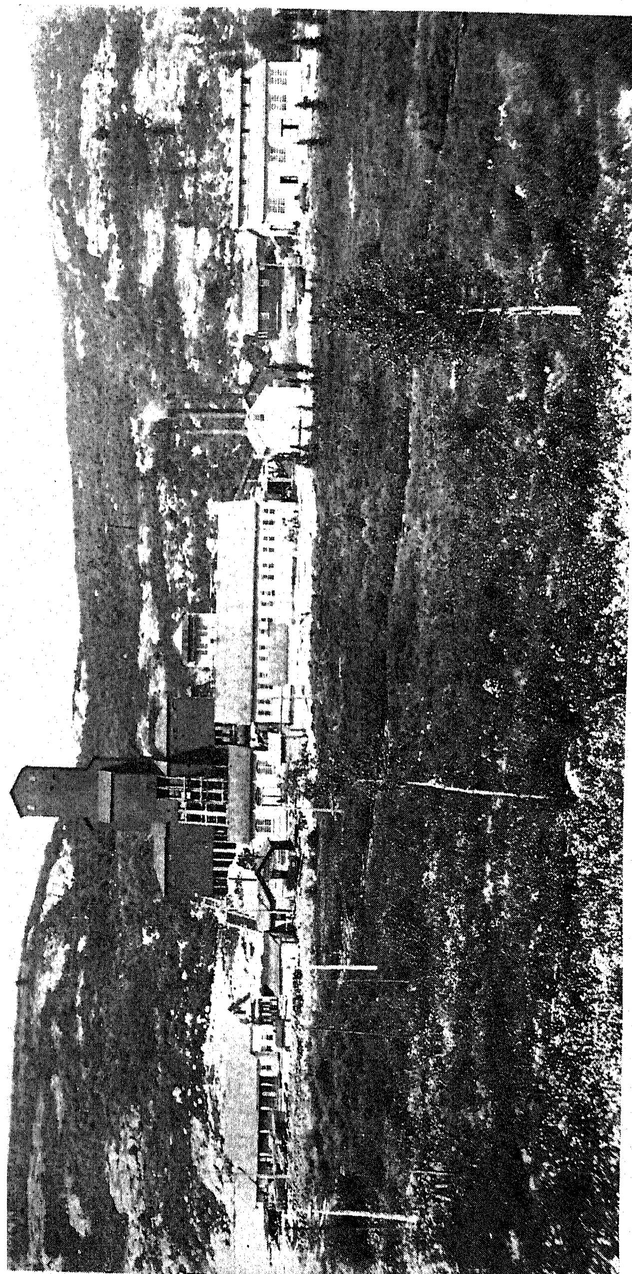

Fig. 39—Levack mine, Sudbury area, Ontario, August 28th, 1916.

Although the Levack ore body occurs near the norite, it nevertheless is found wholly in the granite-gneiss, this rock forming both footwall and hanging-wall, Fig. 40. The norite occurs from 40 to 220 feet, or an average of about 175 feet from the ore body, measured at right angles to the strike and dip of the norite.

No commercial ore occurs in the norite, but this rock is lightly "spotted" with sulphides near the contact.

In August 1916 mining was being done on the first, second and third levels, the depths of which were 150, 250 and 350 feet respectively. An irregularly shaped ore body occurs on the first and second levels, about 300 feet southwest of

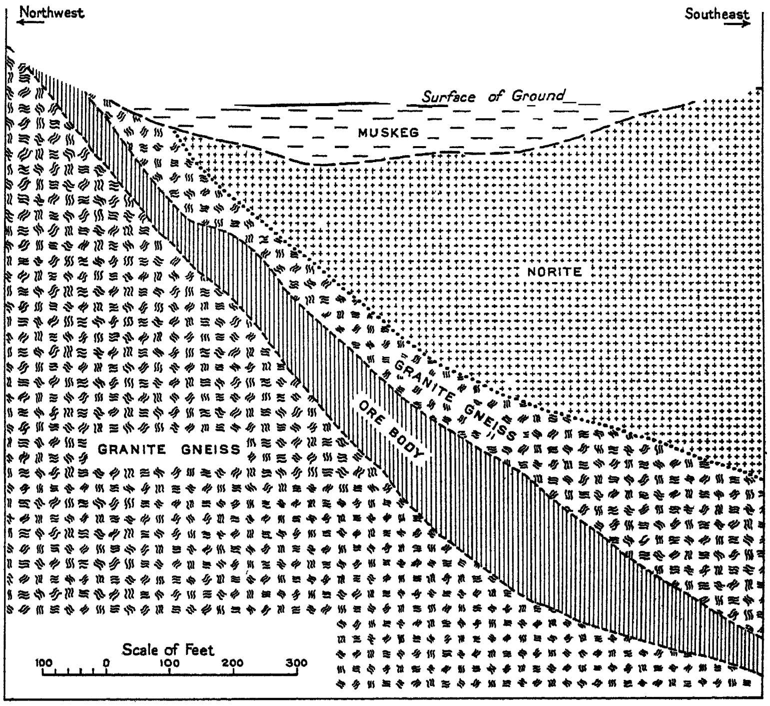

Fig. 40—Levack ore body, Sudbury area, Ontario, showing how the deposit occurs in the granite-gneiss.

the shaft. On the third level this ore body becomes larger and assumes a somewhat lenticular form, having a length of 500 feet or more, and a maximum width, measured horizontally, of 150 feet. On this level, about 160 feet northeast of the shaft, there is a triangular-shaped ore body which projects into the granite-gneiss footwall about 340 feet. These two ore bodies do not seem to be connected on this level. Below the third level no development work had been accomplished at the time referred to, but diamond-drill cores showed that the ore body extends to a depth of nearly 1,300 feet measured along the dip.

The Levack ore body is a replacement or impregnation deposit in granite-gneiss. It is evident that the granite-gneiss was fractured and brecciated, so that

the introduction of the sulphides was readily accomplished. The sulphides occur in irregular masses, in veinlets, and in disseminated grains. The larger, irregular masses of sulphides may be several feet in diameter and be made up of almost pure ore, with only specks of rock fragments enclosed. Sometimes these large masses of sulphides enclose boulders of rock of various shapes and sizes, Fig. 41. These boulders in the ore body are not, however, as common and characteristic as they are at Creighton, Worthington and elsewhere. The sulphides occur for the most part disseminated through the gneiss in a very irregular fashion, Fig. 42. All gradations are found between gneiss which is but slightly replaced or impregnated with ore, and gneiss which has been almost wholly replaced. Granite-gneiss "spotted" with sulphides often occurs.

There are no sharp walls on either the hanging-wall or footwall. Mineralization gradually becomes less intense as the walls are approached. Mining ceases

Fig. 41—Character of ore at Levack mine, Sudbury area, Ontario, first level. Black represents sulphides; white represents granite-gneiss. Width of face 3 feet.

when the grade of ore becomes too low to pay. As is to be expected the commercial ore body contains many masses of almost barren rock.

Above the commercial ore body the hanging-wall is impregnated with ore for 50 to 350 feet measured at right angles to the dip and strike of the deposit. The mineralization becomes less and less intense as the distance from the ore body increases. The norite itself is "spotted" with ore for 25 to 250 feet from the contact with the granite-gneiss, measured at right angles to the dip and strike of the contact. The footwall below the ore body, on the other hand, appears to be mineralized only for 50 or 60 feet beyond the limits of the commercial ore body.

About 33 per cent. of rock is hand-picked from the ores, but the hand-picked ore still contains 14 per cent. of silica.

The sulphides were probably introduced by means of hot aqueous solutions which circulated through the brecciated granite-gneiss and deposited the sulphides in every crack and crevice, replacing and impregnating the granite

gneiss. The feldspar of the granite-gneiss retains its fresh appearance; in other words, the introduction of the sulphides appears to have produced little or no alteration in the granite-gneiss or, indeed, in the norite.

Fig. 42—Character of ore at Levack mine, third level, Sudbury area, Ontario. Black represents sulphides; white represents granite-gneiss. Width of face 1 foot. The sulphides replace or impregnate the granite-gneiss.

The Victoria Ore Bodies

The Victoria mine is notable on account of the fact that it has been worked to a greater depth than has any other nickel-copper deposit in the Sudbury field, and, in fact, to a greater depth than any other mine in the Province of Ontario. Although the deposit is not, relatively speaking, a large one, it is nevertheless a persistent and important one. The main shaft is located on the north part of lot 8 in the fourth concession of Denison township, and the mine is served by the Algoma Eastern railway.

The oldest rocks in the vicinity of the mine are schistose quartzites, greywackés and slates of the Timiskaming series. These have been intruded by greenstones, fine to medium in grain. In rare cases the greenstones have amygdaloidal textures and pillow structures showing that some were formed at or near the surface of the earth. The norite intrusion then followed. It was invaded by granite dikes a few feet in width. The formation of the ore bodies then took place. Finally, the geological history of the area, in so far as it treats of pre-Cambrian rocks, was closed by the intrusion of olivine dibase dikes which have not yet been found on the surface, but which intersect the ore bodies in the lower levels of the mine.

The norite, like that at the Garson, is somewhat metamorphosed, with the result that it has often been altered to a gneiss or schist. On the whole it has a more ancient and altered appearance than the norite at the Creighton or Murray mines. There are no workings which show the nature and dip of the contact between the main mass of the norite and the adjacent rocks. However, along the contact of the norite between Victoria and Crean Hill mines, a distance

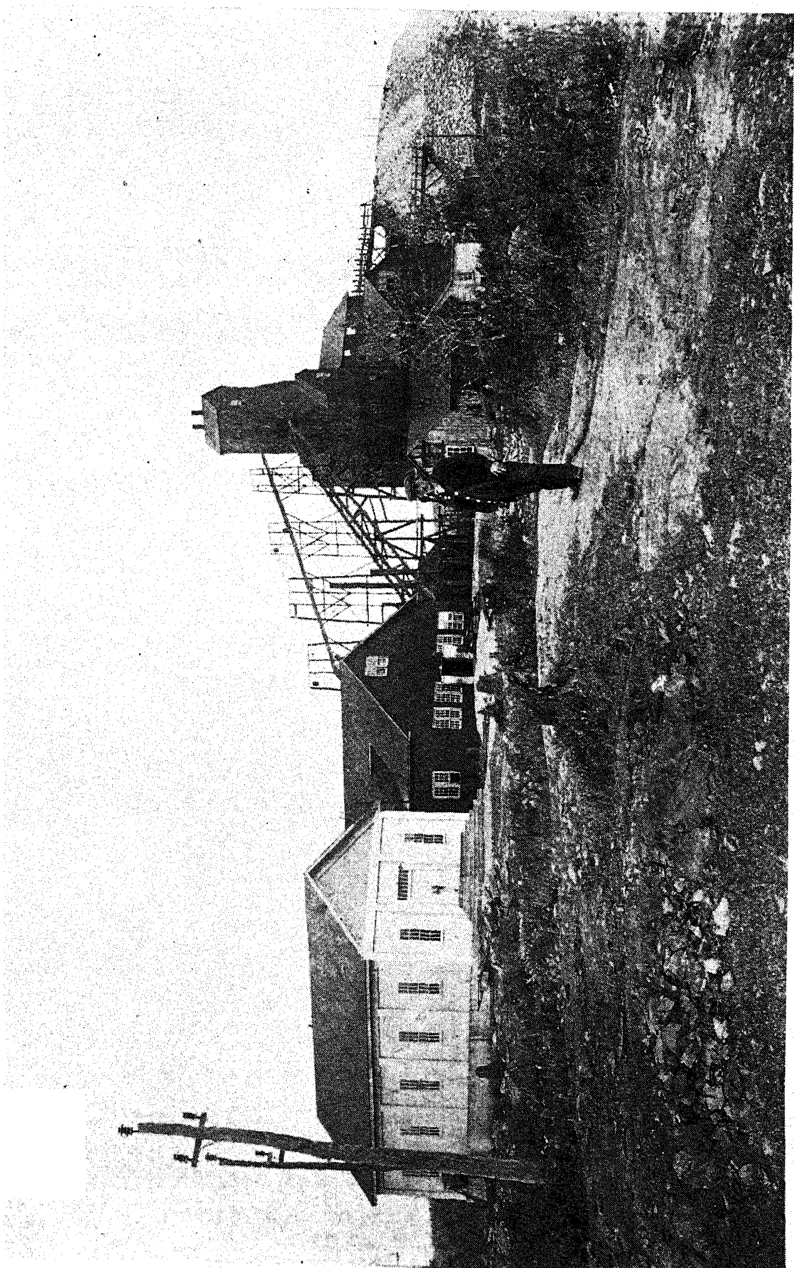

Fig. 43—Victoria mine, Sudbury area, Ontario, October 10th, 1916.

ıt two miles, the rock adjacent to the norıte is sometimes quartzıte or grey- The beddıng of these sediments at the contact is more or less vertical, so the norite follows the beddıng planes ın ıts downward extensıon, ıt wıll a more or less vertical dip. The workıngs at Crean Hıll prove that the is more or less vertical.

ıe ore bodıes occur about at the intersection of a northwest-southeast and a st-southwest zone of shearing, crushıng and mineralızatıon. The main ies of the Victorıa mıne are found on the northwest-southeast zone of dıs- e; in addıtıon to the main deposıts which are beıng worked there are several deposits on thıs zone to the northwest and southeast of the shaft which en prospected to a minor extent by shafts and other workings.

e northwest-southeast zone of shearing, crushing and mıneralization is the nportant one ın connectıon wıth the Victoria mine. Crush-conglomerates ısh-breccıas are found along it at various points, and the mıneralized zone ıngth of more than three-quarters of a mile. It follows the contact of the norite and adjacent greenstone for half a mile to the northwest of the shaft, along which part both of these rocks, norıte and greenstone, are often altered to schist or gneıss at the contact, so that ıt may be dıfficult at times to decıde where one rock begins and the other ends. In thıs part northwest of the shaft the mineralızed and sheared zone has a wıdth of as much as 300 feet in places. To the southeast of the shaft the mineralized zone leaves the norıte contact and passes into the green- stones, extending for about one-thırd of a mıle or more to the southeast. In this part of the mineralized zone there are two or more small, irregular intrusions of a rock which looks lıke norıte but which appears to have no surface connectıon with the maın mass of the norite to the north.

Along the entire length of this mıneralızed zone the rocks, whether they are norıte or greenstone, have been impregnated or replaced by sulphides and to a less degree by calcıte and quartz. The sulphides ın the non-economic portıon are present in dissemınated grains, ın ramifyıng veinlets, or irregularly shaped masses. The extensıve workıngs, to a depth of 2,312 feet, have shown that this zone has a vertical dıp. The shaft has a depth of 2,618 feet.

The economıc part of the zone consists of two distinct ore bodies which have been named the west ore body and the east ore body. They are found about the centre of the mineralized zone. The west ore body has been mıned to a depth of about 2,312 feet, the sıxteenth level, the east ore body to a depth of about 1,200 feet. The workings at these depths are stıll in ore. These ore bodies are from 80 to 185 feet apart, Fig. 44. The length of the west ore body varıes from 60 to 150 feet. The east ore body is smaller, ıts length being from 65 to 100 feet. The two ore bodies do not appear to have any regular strıke, but they pitch to the southeast at an angle of about 70°, Fig. 44. Both ore bodıes occur ın fine-grained greenstone and quartzıte, or schistose rocks whıch have resulted from the shearing of the greenstone and quartzite. The west ore body is about 200 feet or more south of the maın mass of the norite, whıle the east ore body is found still farther from the maın mass. The crosscuts from the shaft to the ore bodies intersect an intrusion of a rock resembling the norite. This intrusion is on the footwall side of the ore bodies, sometimes removed from them a dıstance of 300 feet, Fig 44.

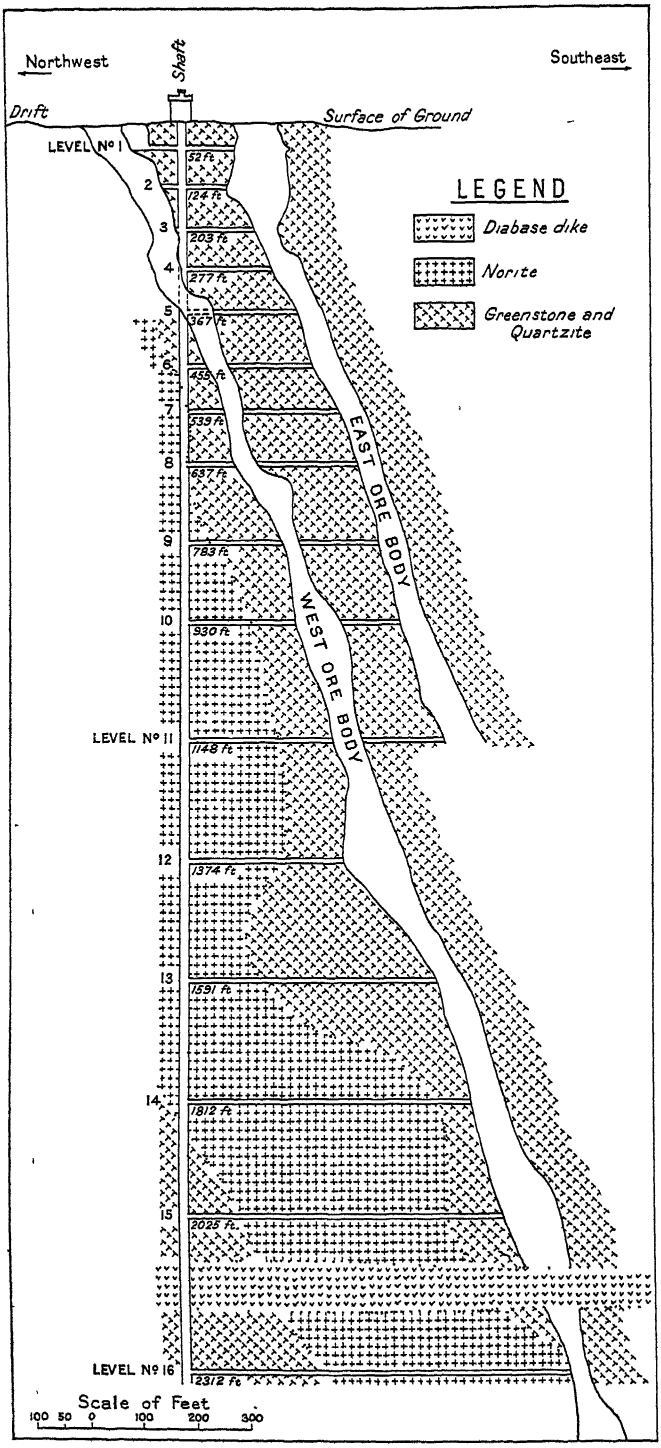

Fig. 44—Cross-section through Victoria ore bodies, Sudbury area, Ontario. At the time this Report was written the Victoria mine was the deepest in the Sudbury area, the west ore body having been worked to a vertical depth of 2,312 feet, and the shaft having been sunk to a depth of 2,618 feet.

In addition to the above economic ore bodies, there is another smaller economic deposit to the southeast. Several thousand tons of ore are blocked out here, but it is not being worked at present. Beyond this, to the southeast, there is a hill which contains economic ore, but which is also not being worked. The rock on this hill is greenstone, and the sulphides are found in disseminated grains and in vein-like occurrences along sheared zones.

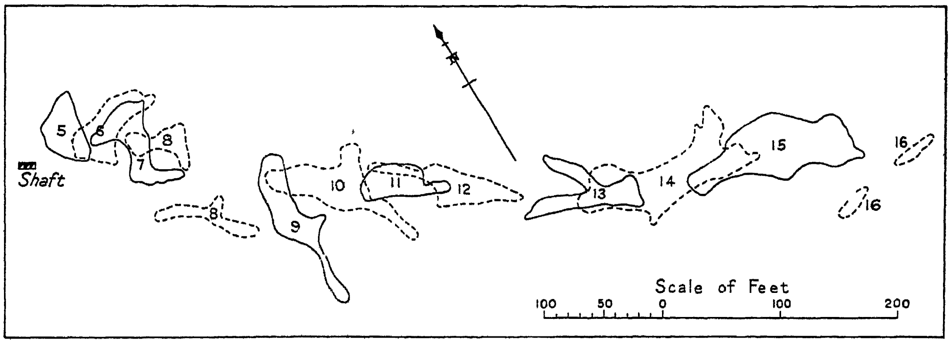

Fig. 45—Composite plan showing size of west ore body on the fifth to sixteenth levels, inclusive, Victoria mine, Sudbury area, Ontario.

The shapes of the west and east ore bodies in the various levels are shown in the composite plans, Figs. 45 and 46. It is to be remembered, however, that these outlines are of commercial ore, and that mineralization, like the mineralization at Creighton, Worthington and other deposits, occurs beyond the limits of the commercial ore bodies. The structure of the two ore bodies is often vein-like,

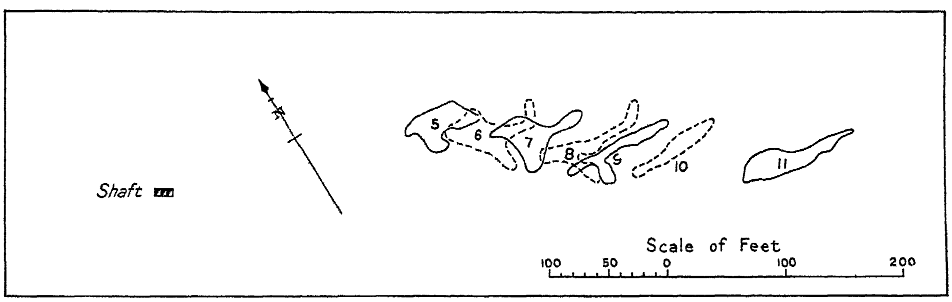

Fig. 46—Composite plan showing size of east ore body on the fifth to eleventh levels, inclusive, Victoria mine, Sudbury area, Ontario.

Fig. 47, the sulphide coming sharply against the wall rock. On the other hand, the wall rock is often replaced and impregnated with sulphides in the clearest manner. Where the wall rock is schistose the sulphides may follow the schistose planes in the process of replacement or impregnation. As a general rule the rocks adjacent to the ore bodies are schistose. Veinlets of ore from the main ore bodies

often ramify in all directions into the wall rock. Like other commercial deposits in the Sudbury field, the west and east ore bodies of the Victoria mine contain great numbers of boulders and fragments of the country rock, the presence of which constitutes proof of the crushing and brecciation which took place before the introduction of the sulphides. These inclusions are of all shapes. Their size varies from microscopic dust to masses several feet in diameter. Sometimes, of course, the massive ore is practically free from these inclusions.

To the northeast of the two ore bodies described above there is a crushed, sheared and mineralized zone extending for a few hundred yards. It occurs in the main mass of the norite at the contact with adjacent rocks. Fine examples of crush-conglomerate and crush-breccia are found along this northeast-southwest zone. It may be added that commercial ore has not yet been discovered here.

On the 2,312-foot level the west ore body is intersected by a dike of fresh olivine diabase which has a width of about 30 feet measured at right angles to the walls of the dike, Fig. 44. It strikes northwestward and dips at an angle of about 65° to the northeast. In a raise some 80 feet above the level the fine-grained edge of the dike may be seen to have chilled against the ore body, proving that it was intruded after the formation of the deposit. While the edges of the dike are dense and fine-grained, the central parts are coarse-grained. On the north side of the dike a well-defined crushed zone, or fault, about two feet or more wide, containing much soft, clay-like material, follows the contact of dike and wall rock, but the crushed material is inside the dike about 3 feet from the edge. Evidently some movement took place along this crushed zone, but its extent and direction were not determined. Similar faults are met with at Crean Hill and elsewhere. The dike is readily distinguished from the wall rocks by its freshness and by the absence in it of seams of calcite or quartz. At the time of examination in August, 1916, the shaft was timbered down to the 2,312-foot level, so that it was not possible to search for the dike in the shaft. It is said, however, to have been met with in the shaft about 260 feet above this level and about 700 feet to the northwest of where it intersected the ore body. The dike has not been found on the surface, although its probable outcrop may be along a northwest-southeast valley which occurs three or four hundred yards south of the shaft house. This valley is drift-covered, and follows the course of a small creek. In addition to the main dike there are small dikes 1 or 2 feet wide intersecting the ore body on the 2,312-foot level and elsewhere in the mine. They are dense and fine-grained, and no doubt directly connected with the main dike. The latter appears to be of the same age and character as the olivine diabase dikes at the Murray, Creighton and other mines.

The Victoria ore bodies, and the northwest-southeast zone of crushing, shearing and mineralization on which they occur, furnish what appears to be a clear example of sulphides which have been deposited from solutions circulating along crushed and sheared zones. While the commercial parts of the west and east ore bodies are indeed sometimes pipe-like, sometimes vein-like, they are nevertheless simply a part of the mineralized zone which extends half a mile to the northwest and about one-third of a mile to the southeast of the main ore bodies The sulphides replace and impregnate the rocks along this zone whether

they are norite, greenstone or quartzite, or their schistose equivalents. Some favourable combination of circumstances tended to produce workable deposits along this zone, resulting in the formation of the west and east ore bodies. The occurrence of quartz and calcite, or dolomite, in the main deposits and along the impregnated zone furnishes evidence for believing in the theory that the ores were deposited from solution, although it may be added that some of the quartz and calcite may have been deposited earlier than the sulphides. The drifts and other workings in the country rock, for instance, have shown that the rocks contain

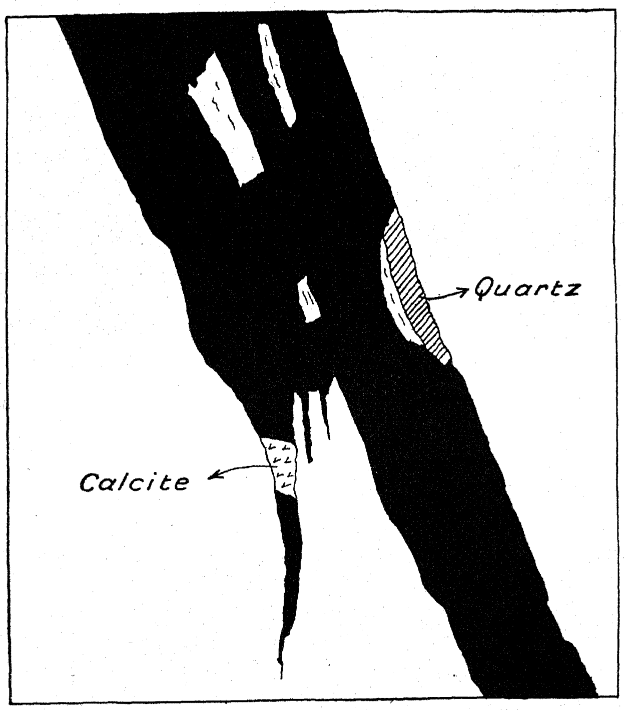

Fig. 47—Character of ore body at Victoria mine at narrow end of a lens, eleventh level. Black represents sulphides; white represents greenstone. Width of face 12 inches. The calcite, quartz and sulphides appear to have been deposited during the same period of mineralization.

many veinlets of quartz or calcite about a quarter or half an inch in width. On the other hand, quartz, calcite and sulphides are often so closely intermingled in the ore bodies and mineralized zone that it seems reasonable to suppose they were deposited during the same period of mineralization.

The ore in the upper levels of the west and east ore bodies contained 3 to 4 per cent. nickel and 2 per cent. copper. As depth was obtained the amount of nickel decreased and the copper increased, until on the lower levels the ore contained 1.5 to 2.5 per cent. nickel and 3 per cent. copper. There is handpicked from the ore about 25 per cent. of rock, and this handpicked product still contains about 14 per cent. of silica.

Between the Victoria mine and the Canadian Pacific railway, about two miles to the south, there are half a dozen or more fahlbands. They have a width of five to as many as 200 feet, and one of them has a length of about two miles. The fahlbands occur in fine-grained schistose rocks which were originally quartzites, greywackés or slates, but are now more or less altered to schists which, however, still retain their bedding planes Sulphides are finely disseminated through these rocks, and the weathered surface assumes the characteristic brown colour due to the formation of iron oxides which result from the decomposition of the sulphides. Of the latter, pyrrhotite and chalcopyrite have been recognized in a small pit about 250 yards southeast of Mond station on the Algoma Eastern railway. The pit in question is about 50 feet south of the waggon road.

The fahlbands, however, probably contain on the average only traces of nickel and copper. The mineralization follows the strike of the bedding planes which are about northwestward. Their dip is more or less vertical. Crushing has often taken place along the fahlbands, as, for instance, that one which occurs at the intersection of the waggon road to Victoria and Crean Hill mines on lot 7 in the third concession of Denison. Crush-breccias and crush-conglomerates occur here and there along this fahlband.

The fahlbands were in all probability formed by hot solutions circulating along bedding planes, and depositing sulphides. The crushing no doubt aided in the circulation of the solutions. It seems evident that the fahlbands were formed during the same period of mineralization as that in which the Victoria ore bodies were deposited. Indeed, the northwest-southeast zone of mineralization, of which the west and east ore bodies of the Victoria are a part, is really of the nature of a fahlband.

The Worthington Ore Body

The Worthington mine is situated about 25 miles west of the town of Sudbury, on the Sault Ste. Marie branch of the Canadian Pacific railway. Like the Murray mine, the railway cut was blasted into the ore body, and the track was thus laid on top of the deposit. The mine occupies part of lot 2 in the second concession of Drury township.

The deposit is one of the simplest in the Sudbury area, it being merely a mineralized dike, similar to No. 2 mine of the Canadian Copper Company. It has been called an offset deposit.

The geological story may first be related. The most ancient rocks in the environs of the mine consist of beds of slate, quartzite, conglomerate and greywacké of the Timiskaming series. These sediments have been tilted into nearly vertical positions, Fig. 49, until they now dip at an angle of about 72° to the southeast, their strike being about northeast and southwest. The beds, which were much altered and more or less schistose, were then intruded by greenstone, which is also sometimes considerably altered but still retains its massive structure. The greenstone, for instance, about half a mile northeast of the mine, has been changed to a rock consisting largely of actinolite. It appears to have been, before alteration, a diorite or other closely related rock. The intrusion of the greenstone was followed by the formation of a fissure which apparently followed in part the strike

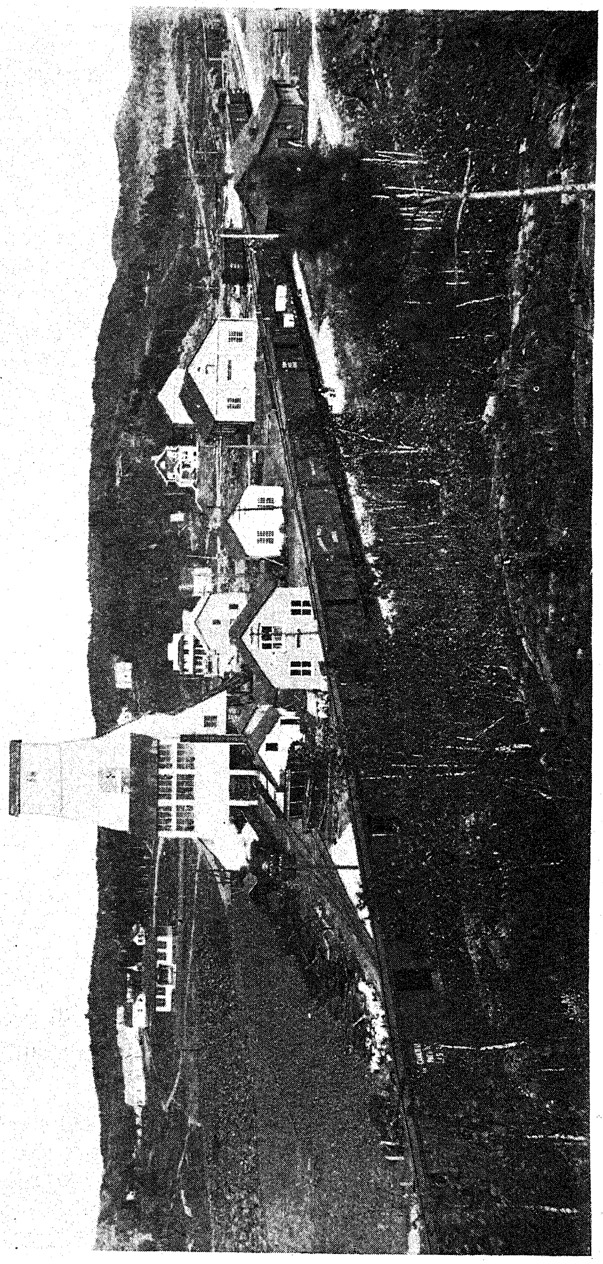

Fig. 48—Worthington mine, Sudbury area, Ontario, September 16th, 1916.

and dip of the sedimentary beds and, in part, intersected the bedding planes. It also cut through the greenstones. Along this great crack a dike, which has been named norite by Coleman, was erupted. The dike is a fine-grained rock from 125 to about 180 feet in width. It is characterized by the amazing number of rock fragments which it has caught up during its intrusion. These fragments consist of various kinds of greenstone, together with fragments of the sedimentary rocks. The most common inclusions are the actinolite rock, and, indeed, in that part of the dike which constitutes the ore body, these actinolite inclusions form 50 per cent., if not more, of the dike. The inclusions are round or angular, and vary from small specks to great blocks 25 feet or more in diameter.

Below are given three analyses of the norite. Nos. 1 and 2 are from various workings of the Worthington mine, while No. 3 is from the Totten mine, about half a mile southwest of Worthington.

Table showing Chemical Composition of "Norite" at Worthington and Totten Mines.

	No. 1.	No. 2.	No. 3.
SiO_2	57.40	54.90	57.98
Al_2O_3	15.61	19 02	18.94
Fe_2O_3	....	5.00	2 24
FeO	10.02	8.51	6 93
CaO	5 45	5.90	5.71
MgO	4.49	1.68	1.84
Na_2O	....	1.99	2.01
K_2O	....	1.72	2.45
H_2O	....	1 81	0.98
CO_2	....	Trace	0 52
		100 53	99.60

Analysis No. 1 in the above table is by the Mond Nickel Company; analyses Nos. 2 and 3 are by W. K. McNeill.

After the norite dike had solidified it was crushed and brecciated along its central portions, for a width of 50 or 60 feet, the width of the ore body, and crush-breccias and crush-conglomerates were formed. Norite and its greenstone inclusions were alike crushed and brecciated, but both rocks retained for the most part their non-schistose character. Then followed the introduction of the sulphides, the latter cementing the fragments together and filling the cracks and other openings in the rocks, Fig. 49. This mineralization was accompanied by some replacement and impregnation of the norite and its inclusions. Little or no mineralization occurs in the slates, quartzites and other rocks of the Timiskaming series.

When the period of mineralization ceased, or about ceased, the norite dike and sedimentary rocks were fissured in two places, and dikes of trap were intruded. The larger of these occurs to the southwest of the shaft and beyond the commercial ore body; it may be seen a few feet south of the railway track. It has a width of 17 feet or more at the widest point exposed, but gradually becomes smaller in about 150 yards to the west, where it finally narrows down to only a foot in

width. It strikes about east and west and dips at an angle of 66° to the south, in so far as surface exposures indicate. If the dike continues in depth with this dip, it will not intersect the ore body since the latter has a still deeper dip of 72°. The second trap dike occurs about 125 feet south of the first. It is only 6 or 8 feet

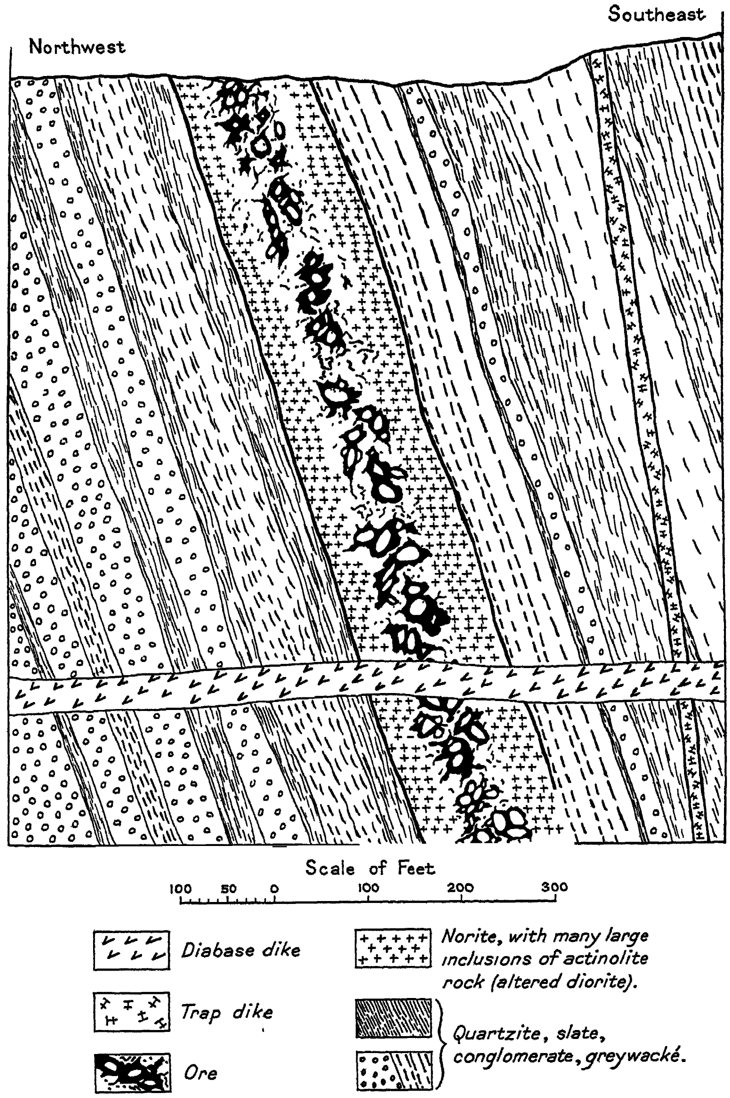

Fig. 49—Diagrammatic vertical cross-section, showing Worthington ore body, Sudbury area, Ontario. The deposit occurs in a dike which has been crushed into round fragments. After the crushing the ore was introduced into the spaces between the rock fragments.

wide and strikes about parallel to the first. Its dip, however, appears to be steeper, some 80° to the southward, judging from surface indications only. These two dikes have not yet been encountered in mining operations, showing that the larger of the two, at any rate, dips away from the ore body. The smaller of the dikes

may be seen intersecting the slightly mineralized norite on the hill southwest of the shaft about 500 feet. It has chilled against the norite and against the sulphides, which would indicate that it is younger than the ore. The larger of the trap dikes is drift-covered where it crosses the norite dike, but it is inferred from its resemblance to the second dike that it also is younger than the norite and ore. These trap dikes are probably of the same age as those at the Creighton mine. C. H. Hitchcock was the first observer to note their presence at the two mines in question.

The traps at the Worthington are fine-grained basic rocks with a dark green colour. A diabase texture was noted in one instance. The following is a partial analysis by the Mond Nickel Company of the larger of the two dikes:

Composition of Trap Dike at Worthington Mine.

SiO_2	55.37
FeO	12.99
Al_2O_3	15.30
CaO	7.75
MgO	4.35

After the intrusion of the trap dikes the rocks in the vicinity of the mine were again fissured, and six or more dikes of diabase, resembling in texture and appearance the olivine diabase dikes at Murray, Creighton, Garson, and other places, were intruded. The diabase is a fresher rock than the trap dikes. A diabase dike intersects the Worthington ore body at its eastern end, having been encountered on the first, second and third levels. It is about 35 feet wide and dips steeply to the northeast, cutting the ore body about at right angles. Another diabase dike striking to the southeast occurs some 450 feet southwest of the shaft. It is dipping at about 45° to the northeast, and will, if it continues at that dip, intersect the ore body in the underground workings, though it had not been met with there in the autumn of 1916. A chemical analysis by the Mond Nickel Company of the first-mentioned diabase dike, which intersects the northeast end of the ore body, gave the following results:

Composition of Diabase Dike at Worthington Mine.

SiO_2	49.05
FeO	14.91
Al_2O_3	16.96
CaO	7.75
MgO	5.27

Small dikes, emanating from this diabase dike, intersect the second trap dike described above.

The final chapter in the geological history of the ore body appears to be closed by the formation of veins, containing calcite, galena, zinc blende and iron pyrites. The veins are 1 to 6 inches wide. That some of these veins were formed at a very much later period than the ore body is shown by the fact that one of them intersects the diabase dike on the first level at the east end of the ore body.

There are numerous slips and crushed zones intersecting the ore body in various parts of the mine. Many of them are at right angles to the strike of the ore body, and dip to the southwest.

The deposit has a length of about 700 feet and a width of 50 to 60 feet. It is being worked to a depth of 438 feet—the third level—but diamond-drill cores have demonstrated that the deposit extends to greater depth. Although the commercial part of the deposit is about 700 feet long, non-commercial mineralization has extended far to the northeast and southwest of the workable ore. The latter is confined chiefly to a central zone in the norite dike.

From what has been said, it is probable that the reader already has grasped an idea of the nature of the deposit. The walls of the ore body are commercial, no sharp lines being found between workable ore and wall rock. The ore consists of: (1) rock fragments cemented by sulphides, Fig. 49; (2) small veinlets of ore ramifying through the rock; and (3) disseminated "blebs" or grains in the rock. The rock fragments consist of norite and its greenstone inclusions, and it is evident that both norite and greenstone were brecciated and crushed prior to the introduction of the sulphides. The disseminated "blebs" or grains are confined largely to the norite.

The ore body is one of the most rocky in the Sudbury field, and, as a result, it is necessary to hand-pick 60 per cent. of rock from the ore. Even this hand-picked material contains about 26 per cent. of silica. The hand-picked ore, however, carries a little less than 7 per cent. of copper and nickel in the proportion of 4 of copper to 3 of nickel, making it the richest ore produced from the mines which were working in the summer of 1916. The unusually high percentage of nickel is due to the large amount of pentlandite in the ore, pentlandite containing about 22 per cent. of nickel.

In addition to pentlandite, gersdorffite and niccolite also occur in the ore body.[1] The ore-bearing minerals are associated with small amounts of quartz which appear to have been deposited at the same time as the sulphides. The presence of quartz has a bearing on the origin of the ore, since quartz is often a water-deposited mineral.

The origin of the deposit appears to be due to hot waters circulating along the crushed and brecciated norite dike. These solutions carried sulphides, quartz and other minerals, and deposited their mineral contents in the cracks and spaces between the crushed rocks.

The Murray Ore Body

The Murray mine is on the main line of the Canadian Pacific railway, about three miles northwest of the town of Sudbury, on lot 11 in the fifth concession of McKim township. It is one of the important deposits of the area, there having been proved, by diamond-drill cores, some 9,000,000 tons of ore.

The oldest rocks in the area consist of greenstones. There are two main varieties, of which the most abundant is a fine-grained type containing numberless veinlets of hornblende ramifying through it; this rock at the nearby Elsie mine has well-defined pillow structures and amygdaloidal textures, and has been named sudburite.

[1] The Nickel Industry, 1913, p. 47.

A complete rock analysis[1] of sudburite is shown in the table below. The analysis is by J. H. Horton.

Table Showing Chemical Composition of Sudburite from the Murray Mine.

SiO_2	46.69
Al_2O_3	14.23
FeO	12.82
Fe_2O_3	2.00
CaO	13.32
MgO	8.15
P_2O_5	0.19
TiO_2	1 28
Na_2O	0.98
MnO	0 11
S	0 12
H_2O	0.08
	99.97

The second variety of greenstone may be called a gabbro or other closely related rock. It has a green colour, and occurs as a belt between the sudburite and the norite, having a maximum width of 350 feet. The rock resembles the gabbro at Frood and Mount Nickel mines. It is of importance because the ore body, in so far as may be judged from the excellent surface exposures, occurs almost wholly in it. The age relations between the gabbro and greenstone are obscure. There are some contacts between the two rocks showing a sharp junction; other contacts are vaguely defined. In addition to the fine-grained greenstone and the gabbro, there is a dike of green diabase, on the hill to the south of the mine, cutting the greenstone. This diabase appears to be older than the olivine diabase dikes later to be mentioned, although the two varieties of diabase were not seen in actual contact. Finally, there is a coarse-grained feldspar-porphyry which has been encountered in the shaft and on the surface. Its relation to the fine-grained greenstone and gabbro was not definitely determined, although it appears to have a dike-like form. It may be added that the greenstones contain inclusions of greywacké or quartzite of the Timiskaming series; these inclusions are, of course, older than the greenstone or gabbro.

The next youngest rock in the area is the norite. That it is younger than the gabbro referred to in the preceding paragraph is proved by the fact that it has caught up blocks of this rock. Good exposures showing the contact between the two rocks may be seen a few hundred yards east of the Canadian Pacific railway track. The gabbro, while resembling the norite, has a distinct, characteristic green colour.

After the norite had solidified there was erupted a mass of granite about 3 miles long and a mile wide. It literally cuts to pieces the fine-grained greenstone and the gabbro with a network of dikes, some of which extend up to the norite and penetrate that rock for 100 or 200 feet.

When the granite had solidified, the gabbro and in part the greenstone along the edge of the norite were crushed, brecciated and broken into a great crush-conglomerate and crush-breccia. The sulphides were introduced into the spaces between these blocks of rocks, and cemented the fragments together, forming the ore.

[1] Ont. Bur. Mines, Vol. 23, Part I, p. 216.

The final chapter in the geological history of the Murray ore body was closed by the formation of great fissures extending across the country for seven or eight miles. Dikes of olivine diabase were erupted through these great cracks, penetrating not only all the rocks mentioned but also the ore bodies. They are probably younger than the dike of green diabase mentioned before.

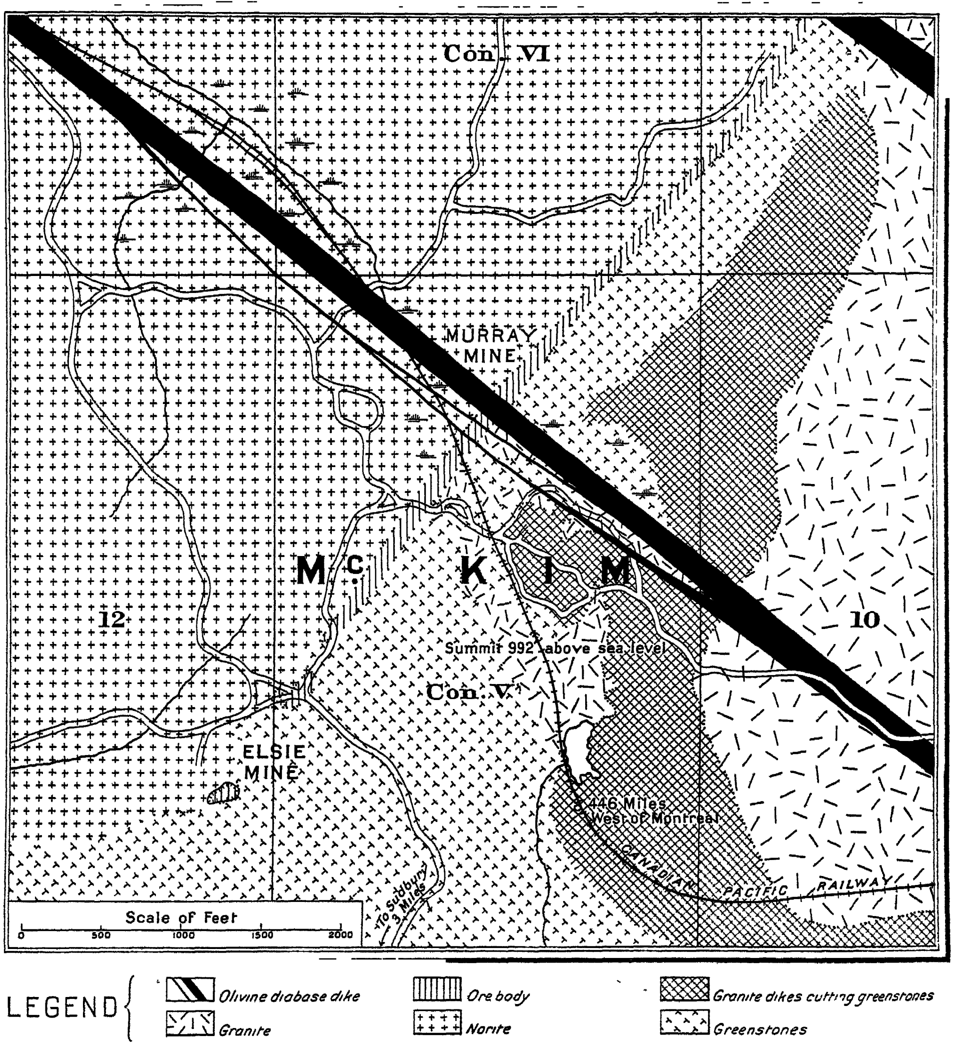

Fig. 50—Geological map after A. E. Barlow, showing Murray and Elsie mines. The left side of the cut is west, the right side is east.

The Murray mine has not been worked for many years, so that an examination of the underground workings was not possible. The character of the ore body, however, is excellently shown in the railway cut of the Canadian Pacific railway, which penetrates across the deposit about at right angles to its strike. It is seen to consist of a mass of gabbro fragments, round or angular, cemented by sulphides.

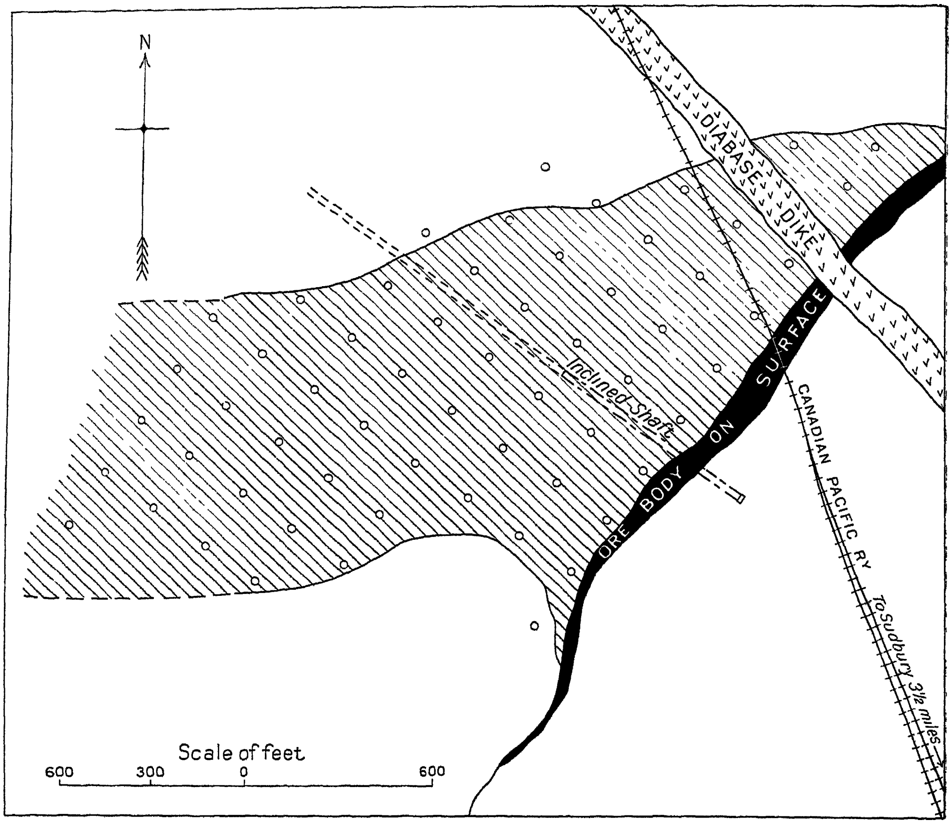

Fig. 51—Map showing Murray ore body, Sudbury area, Ontario. The shaded area denotes the known extent of the deposit below the surface; the ore body dips to the northwest at an angle of 36° as shown in Fig. 52. The small circles indicate diamond drill holes. From drawing by the British America Nickel Corporation.

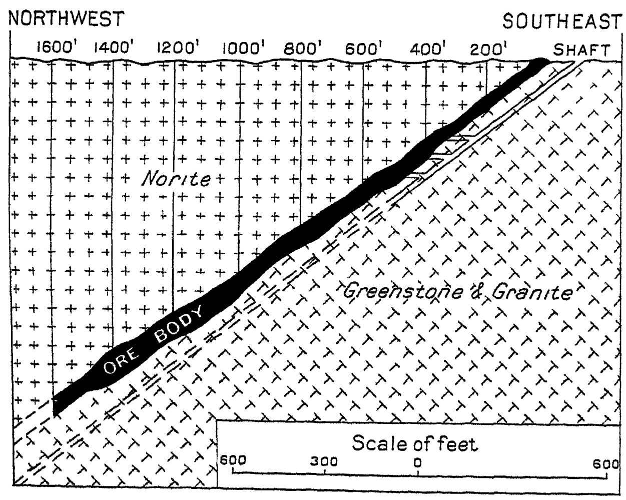

Fig. 52—Vertical cross-section through Murray ore body, Sudbury area, Ontario, showing depth of diamond drill holes. While the ore body occurs about at the contact of the norite and footwall rocks (greenstone, granite and gabbro), nevertheless the Murray ore body is found in the footwall rocks—not in the norite. From drawing by the British America Nickel Corporation.

The ore body occurs almost wholly in the gabbro, but the norite is slightly impregnated with sulphides. Although gabbro and greenstone form the footwall of the upper part of the ore body, drill cores show that granite forms, in part, the footwall in its deeper portions.

The ore body strikes about northeast and southwest and dips at an angle of 36 degrees to the northwest. The deposit extends to a depth of at least 2,000 feet measured along the dip of the ore body. The mineralized zone has a length of 5,000 feet, not all of this being of commercial grade. The average thickness is 50 or 60 feet, measured at right angles to the strike and dip of the ore body. It is estimated that about 33 per cent. of rock will be hand-picked from the ore, and that the hand-picked product will contain about 3 per cent. nickel and copper combined.

Fig. 53—Murray mine, Sudbury area, Ontario, September 2nd, 1916. A modern plant and smelter are being erected at the Murray mine by the British America Nickel Corporation.

A shaft has been sunk to a depth of 700 feet in the footwall, and is being sunk to greater depth. The old workings, made many years ago, were still full of water in the fall of 1916.

The Blezard Ore Body

After being closed for about twenty-three years the Blezard mine was pumped out during July and August, 1916, and diamond drilling begun on the surface. During the time that the property was idle, the smelter, mine and other buildings were burned. The property is on lot 4 in the second concession of Blezard township.

The oldest rocks in the vicinity of the mine are quartzites and greywackés of the Timiskaming series. In greater volume, and possibly younger than the quartzites or greywackés there are fine-grained greenstones which have been called sudburite. The greenstones are sometimes amygdoloidal. That they have undergone a certain amount of metamorphism is shown by the development of red garnets here and there. The very numerous veinlets, fractions of an inch wide, which intersect the rocks, may be of a secondary nature.

In the table below there is given a complete analysis[1] of sudburite from the Blezard by W. K. McNeill.

Table Showing Chemical Composition of Sudburite from Blezard Mine.

SiO_2	46.86
Al_2O_3	16.94
FeO	15.49
Fe_2O_3	4.18
CaO	9.65
MgO	2.94
P_2O_5	0.28
TiO_2	1.54
K_2O	0.23
Na_2O	1.51
S	0.09
H_2O	0.47
	100.18

In addition to the quartzites, greywackés and greenstones, there are irregular areas of a very basic intrusive 50 to 300 feet in length consisting almost wholly of hornblende or pyroxene. Their age relation to the greenstones appears to be obscure.

The norite is younger than any of the rocks above mentioned. It was found, however, that a sharp line of division does not occur between it and the greenstones or basic intrusives. There exists between the norite and the rocks mentioned what may be called a contact zone having a width of 10 to 130 feet. This contact zone consists of a curious intermingling of the norite and greenstones. There appears to have been crushing along the contact zone after the norite had solidified, since blocks of coarse-grained and fine-grained norite are found in it. It may be added that, while an indefinite zone exists between the norite and greenstones, the contact, however, between the norite and quartzite or greywacké is sharp.

The ore body, which is of the marginal type, occurs at the contact of the norité and adjacent rocks, partly in the contact zone referred to above, partly in the fine-grained greenstone and basic intrusive and partly in the norite. Little commercial ore, however, occurs in the norite, the sulphides being sparsely disseminated in grains through this rock, resulting in "spotted" norite. The dip of the norite contact with adjacent rocks is about 50 degrees to the northwest, this representing also the dip of the ore body.

[1] Ont. Bur. Mines, Vol. 23, Part I, p. 216.

The commercial part of the ore body consists of the usual fragments and blocks of rocks cemented together by sulphides. In this respect it in no way differs from other marginal deposits. Veinlets and disseminated grains of sulphides also occur.

The ore body was worked by an open pit and two shafts. The open pit has a length of 200 feet by a maximum width of 120 feet, and a depth of about 35 feet. The main shaft is near the southwest end of the bottom of the pit. It is about 100 feet deep, measured from the bottom of the pit. A small amount of stoping was done from this shaft, a stope about 75 feet in length having been begun by the old miners. The second shaft is on the surface near the north end of the pit. It has a depth of 120 feet, and was not connected with the pit by drifts or any other workings. Two drifts about 30 feet in length occur at the bottom of the second shaft.

In the neighbourhood of 100,000 tons of ore are reported to have been mined, containing 4 per cent. nickel and 2 per cent. copper.

Although an exploration campaign by diamond drill was in progress during the summer and fall of 1916, no attempt was made to work the deposit.

Results of Drilling by the E. J. Longyear Company in the Townships of Falconbridge and Garson, Sudbury Nickel-Copper Area, Ontario*

Introduction

The E. J. Longyear Company, of Minneapolis, Minnesota, has conducted explorations in the Sudbury area with five diamond drills during the year 1916. Holes were drilled in the townships of Levack, Trill, Denison, Blezard, Garson, Falconbridge and MacLennan.

A body of nickel and copper ore was found in lots 10, 11 and 12, in the fourth concession of Falconbridge township. This property lies in the southeastern part of the area, about three miles east of the Garson mine.

Local Geology in Falconbridge Township

Since a discussion of the geological features developed by the exploration is now being prepared by H. M. Roberts and Robert D. Longyear, no attempt will be made in this summary to discuss the mode of occurrence and genesis of the ores. The ore body under consideration occurs along the outer edge of the norite at its contact with older rocks, in this instance, composed of greenstone, greywacké and quartzite. The contact is steep, the dip varying from vertical to 70 degrees northward. In one cross-section the dip has been found to be 85 degrees to the south. The ores are composed of the sulphides, pyrrhotite, chalcopyrite and pentlandite, with varying admixtures of norite and footwall rocks.

The lands are covered with deep kettles and morainic hills, consisting of gravel and boulders, which were left behind upon the retreat of the ice sheet. The surface

* Mr. Hugh M. Roberts, of the E. J. Longyear Company, has kindly furnished the Commissioners with the following description of the diamond drill operations in Falconbridge and Garson townships.

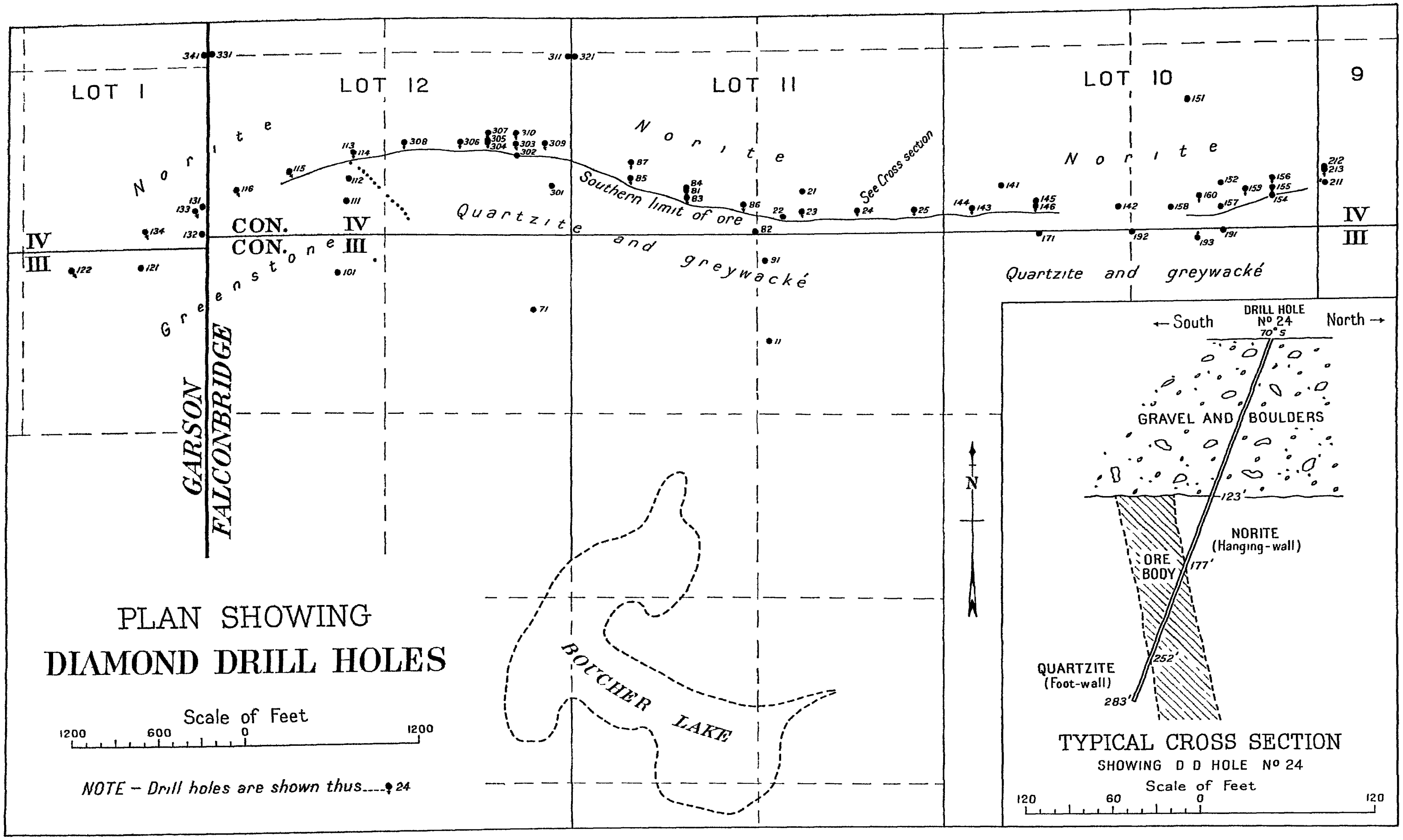

Fig. 54—Plan showing location of ore body which was discovered in the year 1916 by the E. J. Longyear Company in Falconbridge and Garson townships, Sudbury area, Ontario.

covering had heretofore retarded developmnt in this vicinity and presented a serious obstruction to exploration, since all rock exposures were concealed. This increased the hazard of the undertaking and added to the cost of the drilling.

Ore Body

The drills were still at work in January, 1917, in this vicinity, and the limits of the ore body were not yet determined. Thus any description at the present time is necessarily fragmentary.

An accompanying map, Fig. 54, shows the drill holes which were completed before January 1, 1917. The position of the ore body, as thus far indicated, is also shown on this map. The map also shows a typical cross-section of the ore body. The ore is believed to extend from the east line of lot 10 to the west line of lot 12, a distance of one and one-half miles, and has been crossed at intervals of 200 or 400 feet, excepting in the vicinity of the centre of lot 10, where holes have not yet been drilled. The horizontal width of the ore body varies from a minimum of 10 feet to a maximum of 150 feet.

During the conduct of the exploration, it was planned first to outline the norite contact by means of vertical holes, which would merely penetrate rock. After this preliminary "scouting," angle holes were planned to cross the contact for the purpose of finding ore and to determine its extent and quality.

The appended tables, in the appendix, summarize the information obtained from the drill holes which penetrated ore.

Sampling

The method of sampling may be briefly described. During the course of the drilling, 90 to 95 per cent. of the core was recovered. This core was split longitudinally by means of a "core-splitter" devised for the work; one-half was kept on file as a record of the physical characteristics of the ore and the other half was ground for analysis. In pure ore, intervals of five feet were analyzed. In mixed ore and rock the division points were chosen according to the character of the material; but in no case was a smaller interval than six inches analyzed, or a greater interval than five feet.

Summary

Owing to the incomplete state of the exploration, it is obviously impossible to give any statement of tonnages or of average metallic content. General ideas along these lines may be best obtained from inspection of the tables, the map and the typical cross-section.

The ore body, as thus far disclosed, varies in width from 10 feet to 150 feet; the metallic content varies from 1 to 5 per cent. in combined copper and nickel. Subsequent drilling may alter these figures. No deep drilling has been projected as yet. The present work merely indicates the remarkable extent and continuity of the deposit. The greatest depth at which ore has been cut is 580 feet. There is no geological reason why ore may not be expected to extend to far greater depth.

OTHER NICKEL-COPPER DEPOSITS, SUDBURY*

On preceding pages descriptions are given of deposits that were being worked in the year 1916. In following pages deposits that were not being worked in that year will be discussed.

THE SOUTHERN NICKEL RANGE

Of the ore bodies on the southern nickel range, ten have already been described, under the heading of working mines; namely, Worthington, Victoria, Crean Hill, Vermilion, Creighton, No. 2, Murray, Blezard, Garson and Longyear. Reference will now be made to the other ore bodies. They are of the marginal and offset types, and were not being worked in the autumn of 1916. The deposits will be described, following Coleman's procedure, by beginning with those that occur at the west end of the norite-micropegmatite and following the basic edge of that rock northeasterly to the eastern nickel range.

Sultana and Sultana East Ore Bodies

The series of pits and small shafts which have been designated as the Sultana mine, occur mostly on lots 7 and 8, in the first concession of the township of Trill. The deepest shaft is said to have been sunk to a depth of 110 or 120 feet. The series of pits and exposures of ore show that the zone of mineralization has a length of about three-eighths of a mile. These ore bodies occur largely in the greenstone. The character of the ore is shown in one of the pits, where it may be seen that it consists of fragments of greenstone cemented together by sulphides.

The Sultana east property is about half a mile east of the Sultana, on lots 6 and 7, in the first concession of Trill township. There are some small pits on the claim. The ore occurs in greenstone.

The Chicago Ore Body

The Chicago also known as the Travers or Inez mine, is on lot 3, in the fifth concession of Drury township, about 4 miles north of the Worthington mine.

The ore body occurs in greenstone and a coarse-grained anorthosite, the deposit being about a third of a mile south of the norite-micropegmatite. The ore body was worked by an open cut about 200 feet long and 5 to 25 feet in width; a shaft is said to have been sunk to a depth of 160 feet. At least 3,500 tons of ore were mined from the deposit. The ore body, which strikes northeasterly and dips steeply to the northwest, is veinlike in part. It was evidently formed along a fissured and sheared zone, the rocks being schistose near the deposit. There is an unusual amount of quartz and calcite or dolomite associated with the ore, and this, together with the veinlike character of the deposit and the altered and schistose condition of the wall rocks, show that the minerals, including the sulphides, were deposited from hot circulating waters.

* By Cyril W. Knight.

Ore Bodies between Chicago and Victoria Mines

About a mile southeast of the Chicago mine there is some mineralization near the southeast corner of lot 2 in the fifth concession of Drury township, and near the line between concessions 4 and 5. Stripping and small pits extend for 200 or 300 yards. Farther east, at the north end of lot 12 in the fourth concession of Denison township, ore has been found in several pits.

At the north end of lot 11 in the fourth concession of Denison township, half a dozen pits and strippings have disclosed a considerable body of ore in greenstones and green schist.

The Totten, Worthington No. 2, Howland, Robinson, Gersdorffite and McIntyre Ore Bodies

These ore bodies occur in what is known as the Worthington offset—a dike about four miles long and 100 to 200 feet wide. The dike has the composition of a diorite or other closely related rock, and is thought by certain writers to be connected with the norite-micropegmatite, although there is no direct surface connection with this rock. The ore bodies associated with the dike are much alike; the largest, and the only one which was being operated in the fall of 1916, is known as the Worthington, and is described elsewhere in this report. The commercial ore in all the deposits is of the usual character, and consists largely of fragments of the dike cemented together by sulphides.

At the northeast end of the dike on lot 10 in the third concession of Denison township two pits have been sunk. About a quarter of a mile to the southwest on lot 11 in the same concession there is a pit known as the McIntyre mine. At the Gersdorffite mine, about three-quarters of a mile southwest, there are three small pits; the dike here appears to cut across the bedding planes in the sedimentary rocks, and it pinches out into irregular stringers a short distance to the northeast. The property is at the south end of lot 12 in the third concession of Denison township. Beyond the Gersdorffite, on the north part of lot 12 in the second concession of Denison township, is the Robinson mine, at which a tunnel about 70 feet long has been driven into the hill. The offset here consists of many irregular intrusions ramifying through greenstone, the latter consisting largely of actinolite. Both offset and greenstone are spotted with blebs of sulphides, but the blebs are most common in the offset. Between the Robinson mine and the Howland, the next property to the southwest, the offset contains an enormous number of greenstone inclusions.

The Howland mine is at the north end of lot 1 in the second concession of Drury township. It consists of an open pit about 75 feet long, some 30 feet wide and about 30 feet deep. A dike, 12 inches wide, of a fine-grained, dark-coloured rock cuts across the northeast end of the deposit, while at the southwest end a very large olivine diabase dike appears to cut off the ore body. The deposit consists of angular and round fragments of rock cemented together by sulphides.

Worthington No. 2 is about half a mile southwest of the Howland, on lot 2 in the second concession of Drury township. There is a pit about 200 feet deep at the southeast side of the offset. The offset here is smaller than at the Worthington

mine; it pinches out about 200 yards northeast of Worthington No. 2, and there is a break in its continuity for 300 or 400 yards, before it appears again near the Howland mine. The greenstone at Worthington No. 2, through which the offset cuts, is an actinolite rock; about a quarter of a mile to the east, this rock passes gradually into a diorite or gabbro, thus disclosing the origin of the actinolite rock.

Beyond the Worthington mine, to the southwest, there are several workings along the offset, including the Totten ore body, which is on lot 2 in the first concession of Drury township. Some mineralization is found for a mile to the southwest of the Totten mine.

The Crean Hill No. 2, and adjacent Ore Bodies

The deposit known as Crean Hill No. 2, is at the south end of lot 2 in the fifth concession of Denison township, about a mile and a half east of Crean Hill mine. It is of the marginal type and occurs partly in the norite and partly in the greenstone. Stripping and pits have disclosed a considerable body of rocky ore, and it may be seen that blocks of the norite are cemented together by sulphides, showing that the sulphides were introduced after the norite had solidified. The mineralized zone is about a quarter of a mile in length, and along this zone the norite is partly sheared and brecciated.

Between Crean Hill No. 2 and Crean Hill mine, on lot 4 in the fifth concession of Denison township, there are several test pits in the quartzite where ore has been disclosed near the norite.

To the northeast of Crean Hill No. 2, on lot 1 in the fifth concession of Denison township, and on lot 12 in the fifth concession of Graham township, light mineralization occurs for about 400 yards, some work having been done on the lot in Graham.

The Gertrude Ore Body

The Gertrude ore body, on lots 3, 4 and 5, in the first concession of Creighton township, is of the marginal type and occurs at the contact of the norite and what has been called an "older norite," or sudburite. The latter is finer in grain and more basic than the norite. The mineralized zone is about three-fifths of a mile long, and the ore occurs largely in the rocks adjacent to the norite. A drill hole 120 feet deep showed the ore body to have a dip of 55 degrees to 67 degrees to the northward. It is said that 15 feet of mixed ore and 20 feet of solid ore were found in the drill core. The property has been developed by three shafts and several pits, and in the latter it may be seen that the ore consists of rock fragments cemented together by sulphides. The largest pit has a length of 125 feet by a width of 25 to 50 feet. One shaft has a depth of 120 feet and another a depth of 80 feet. Some of the ore is said to have contained 6 per cent. of nickel and less than 1 per cent. of copper.

Diamond drilling at the Gertrude has disclosed the existence of about half a million tons of ore.

East of the line between lots 2 and 3 in the first concession of Creighton township, where the norite takes a bend to the north, there is said to be a small offset to the south on which some ore has been disclosed by stripping.

The North Star Ore Body

The North Star mine is on lot 9 in the third concession of Snider township, about a mile and a half north of the Creighton mine. The deposit, which has been called a marginal type, occurs at the contact of the norite and granite, there being some greenstone caught up in the granite. Dikes from the granite penetrate both greenstone and norite. The deposit dips at an angle of 75 or 80 degrees to the northwest. A shaft has been sunk to a depth of 375 feet. The ore, which is sharply defined against the footwall, appears to have the character of other ore bodies in the area, since the sulphides have been described as containing rounded boulders and angular masses of granite and greenstone.

To the northeast of the North Star mine light mineralization occurs on lots 7, 6, and 5 in the third concession of Snider township. Small test pits have been sunk on these lots.

Lady Violet, Clarabelle or No. 6, No. 4, and Lady Macdonald or No. 5 Ore Bodies

These four deposits, which have been classified as marginal, are a mile or two north of the town of Copper Cliff, and just to the north of Lady Macdonald lake. The first three are on lot 1 in the fourth concession of Snider township, while Lady Macdonald is on the north part of lot 1 in the third concession of the same township. At the Lady Violet there are two pits at the contact of the norite with greenstone. The deposit is said to contain workable quantities of the precious metals.

The Clarabelle, or No. 6 mine, as it is sometimes called, is about half a mile to the south of the Lady Violet. It occurs in the greenstones, and has been developed by two pits. The ore is associated with quartz, calcite, dolomite, and magnetite, a mass of the latter weighing five tons having been encountered. The deposit is said to have produced 4,000 tons of ore containing about 2 per cent. of nickel and 1.68 per cent. of copper.

No. 4 mine has two large open pits from which 43,700 tons of ore, containing 2.91 per cent. of nickel and 1.26 per cent. of copper have been mined. The deposit occurs largely in the greenstone.

Lady Macdonald, also called No. 5 mine, is at the north end of the lake of the same name. The property, which consists mainly of an open pit, has produced 8,000 tons of ore, containing 2.84 per cent. of nickel and 1.06 per cent. of copper. The ore body occurs largely in the greenstone at the contact of the norite.

The Canadian Copper Company has contributed the following information regarding the ore bodies referred to in the three preceding paragraphs:

The area around No 4 mine, No. 5 mine and No. 6 mine is on the Copper Cliff offset.

To the northeast is the older greenstone which underlies the ore-bearing norite, and to the southwest is a granite gneiss. The southeastern portion of the area is a layer of norite not over 400 feet in maximum thickness, which laps over the greenstone. In the northwestern portion the norite may be deeper.

There is a large gossan area which looks to a casual observer to have good possibilities. The area, upon close examination, shows it to consist of irregularly placed, disconnected patches of lean gossan. The ore is low grade.

The average grade from all holes was: copper, .9 per cent.; nickel, 1.3 per cent There were 17 holes drilled in the area, but this did not accurately outline any regular commercial ore body.

Evans, No. 1, and Copper Cliff Ore Bodies

These deposits have been described as offset ore bodies since they are found in a dike. The latter may be called diorite, consisting as it does of plagioclase, hornblende, quartz and biotite.

The Evans mine occurs on a low hill surrounded by drift about a mile southward from the town of Copper Cliff. Only a few square yards of rusty diorite, together with the rock around the edge of the open pits, is to be seen. The dump shows diorite and greywacké, both spotted with sulphides. Whether the diorite is part of the gabbro mass a few hundred yards to the south or whether it is part of the norite-micropegmatite 2½ miles to the north is not positively known, but it is belived by Coleman to be connected with the norite-micropegmatite.

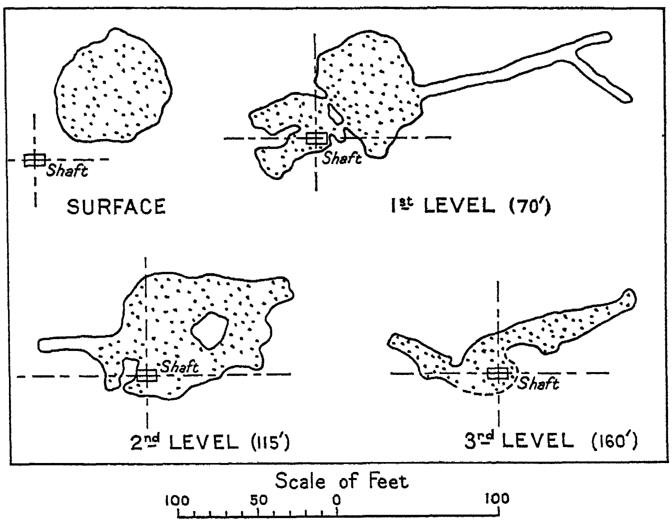

Fig. 55—Plan of old workings showing ore body on the surface to third level, Evans mine, Sudbury area, Ontario. The dotted portions represent "clean" ore.

The deposit has not been worked since 1899, but it was an important producer in the early days of the camp, 234,428 tons of ore having been mined, containing 3 per cent. of nickel and 2.66 per cent. of copper. The ore body was worked by two open pits to a depth of 160 feet, Fig. 55, and by a shaft and other workings to a depth of about 250 feet.

No. 1 mine, which is on the southwestern outskirts of the town of Copper Cliff, and about a mile north of the Evans, consists of five pits which are sunk partly in greywacké and partly in diorite, Fig. 56. The zone of mineralization has a length of a third of a mile and follows an irregular intrusion of diorite, 8 to 50 feet wide, which intersects greywacké and quarzite. The ore occurs mostly in the diorite, but also in greywacké and quartzite. The usual crushed mass of rocks, cemented by sulphides, was noted at a few places. There is also much rock spotted with blebs of ore. Diabase dikes intersect sedimentary rocks, diorite and ore bodies. The series of pits constituting No. 1 mine are said to have produced 23.000 tons of ore containing 3.56 per cent. of nickel and 3.42 per cent. of copper.

The old Copper Cliff mine is situated about the centre of the town of Copper Cliff on a prominent gossan-stained hill.

The deposit occurs in a dike of diorite, Fig. 58, the latter intersecting beds of greywacké and arkose. The diorite is described by A. P. Coleman as consisting of plagioclase, hornblende, quartz and biotite, with more or less titaniferous magnetite, sometimes surrounded with leucoxene and apatite. The width and length of the dike are not known, it being largely covered with drift, but where seen it is 800 feet long and 150 wide. Two small diabase dikes intersect the

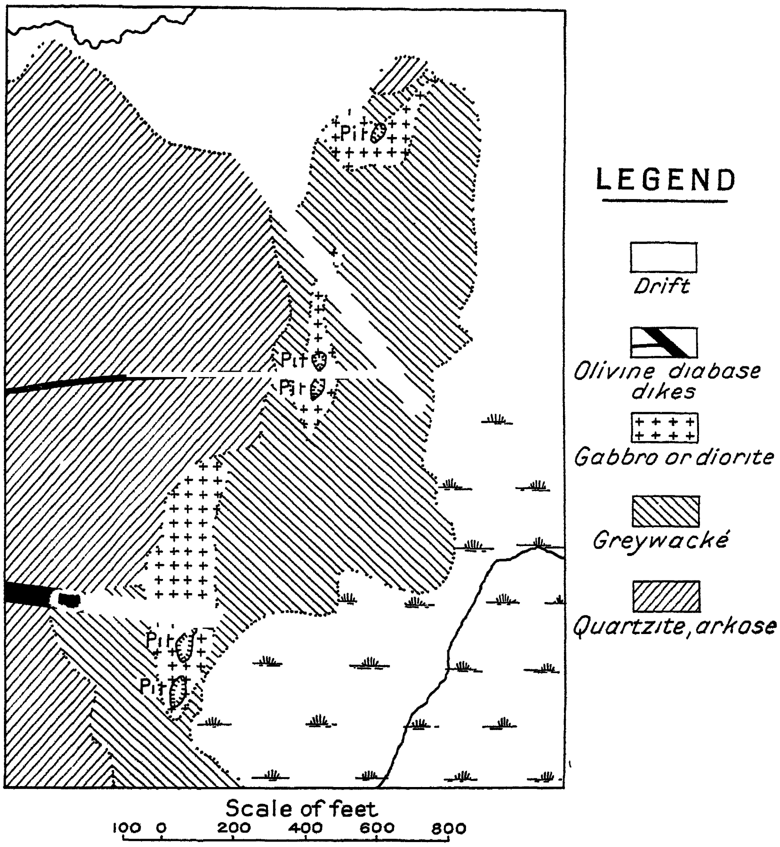

Fig. 56—Geological map of No. 1 mine, Canadian Copper Company, Copper Cliff, Ontario. After A. E. Barlow.

diorite; and two dikes of granite, 6 to 8 feet wide, cut the arkose. A dark-coloured diabase dike, fine-grained, having a width of 25 feet, is said to have been followed from the third to the thirteenth level during mining operations. Small veins of quartz, carbonates, and galena are said to have occurred at the contact of this dike and the mineralized diorite, proving that these veins are much younger than the ore body.

The diorite dike is more or less mineralized where exposed on the hill, but the commercial part of the ore body is much smaller. The following description of the commercial ore body is by A. P. Coleman:[1]

[1] The Nickel Industry, 1913, p. 66.

"The cross sections of Copper Cliff mine and the plans of the different levels, provided by the kindness of Captain Lawson, show that the ore body is a rude cylinder, narrowing and widening from level to level, and forking about 500 feet below the surface. Its longest diameter varies from 75 to more than 200 feet, following the direction of the hill, and the shorter one runs from 50 to 90 feet. As shown in the vertical cross section through the shaft, the somewhat flattened cylinder dips very uniformly at an angle of 77½ degrees towards the east, and reaches a greater depth than 1,000 feet. The earlier shaft following the apparent dip of the outcrop, soon diverged too much from the ore body, and a new shaft was begun at the third level having the dip just mentioned."

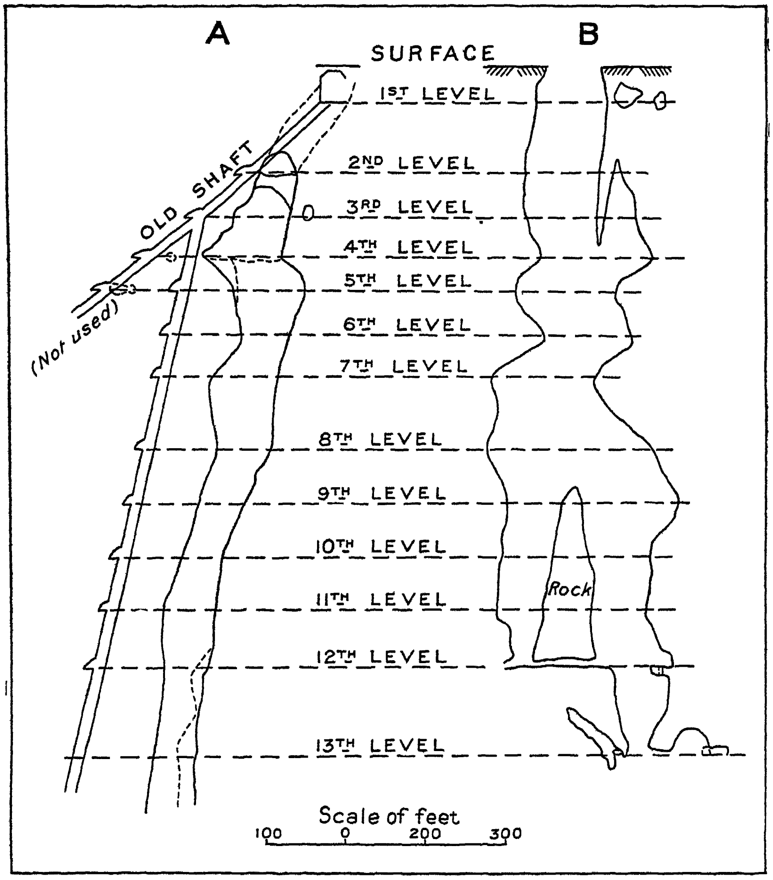

Fig. 57—Showing two sections through Copper Cliff mine, Copper Cliff, Ontario. A is a vertical section through shaft; B is a section at right angles to A. After A. P. Coleman.

The mine was one of the most important in the Sudbury area, having produced 376,739 tons of ore containing 5.13 per cent. of copper and 3.52 per cent. of nickel.

The isolated exposures of diorite in which the Evans, No. 1 and Copper Cliff mines occur are thought by A. P. Coleman to be connected underground by irregular channels with the norite-micropegmatite. The latter occurs about a mile and a quarter north of Copper Cliff mine, on the north shore of Lady MacDonald lake.

A word or two may be added regarding the origin of the sulphides at the Evans, No. 1 and Copper Cliff mines. It has been shown by Dickson, Campbell and others in their microscopic studies that the sulphides replace or impregnate the diorite. Apart, however, from microscopic studies, it is very plain that the ore has been introduced after the diorite had solidified. This is well seen in the old surface workings at Copper Cliff mine, where angular and round blocks of the diorite are cemented together by the sulphides. This condition evidently exists below ground, judging from the verbal descriptions of those who worked in the mine when it was in operation. Evidently the diorite dike, after it solidified, was broken or shattered into crush-breccias and crush-conglomerates and the sulphides were then introduced into the spaces between the fragments or blocks. The sulphides were also introduced in the form of disseminated grains so that the diorite is "spotted" with blebs of sulphides. It has been shown elsewhere, however, that these blebs occur in a variety of rocks, including sediments, and

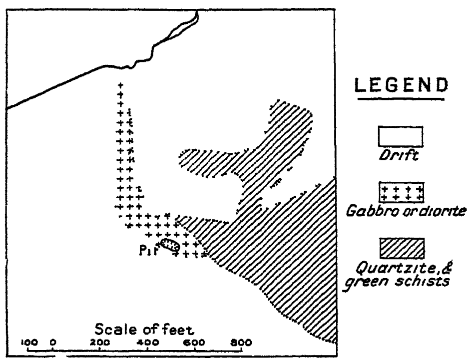

Fig. 58—Geological map of Copper Cliff mine, Copper Cliff, Sudbury area, Ontario. After A. E. Barlow.

that therefore their presence cannot be taken as proof that the sulphides cooled and solidified from the molten diorite. On the contrary, it is believed that the sulphides were introduced by hot circulating waters of magmatic origin.

The Elsie Ore Body

The Elsie mine is on lot 12 in the fifth concession of McKim township about one-third of a mile southwest of the Murray mine. There are two open pits on the property, one about 60 feet in diameter, the other about 130 feet in diameter. It is reported that 40,635 tons of low-grade ore were mined and shipped.

The deposit occurs at the contact of a fine-grained greenstone and the norite. The greenstone shows pillow structure and amygdules, and has been called sudburite, Fig. 59. The ore body appears to be immediately at the contact of the two rocks, the sulphides occurring in both. The ore consists in part of a mass of rock fragments cemented together by sulphides, and in part of veinlets and irregular masses of sulphides ramifying through the cracks in the rocks. The latter are also "spotted" with sulphides.

The Frood and Stobie Ore Bodies

The Frood, also called No. 3, and Stobie ore bodies are situated about two and a half and three and a half miles respectively north of the town of Sudbury. The former occurs on lots 6 and 7 in the sixth concession of McKim township, the latter on lot 5 in the first concession of Blezard township. Although the Frood mine was not being operated in 1916, it is, neverthless, the largest known deposit in the Sudbury area, there being about 45 million tons of ore in the mine, estimated mainly by diamond-drill cores. The ore is, however, lower in grade and more "rocky" than the Creighton deposit, the next largest ore body in the Sudbury area. The Frood ore contains about 3.5 per cent. of nickel and copper combined, in the proportion of 2..05 of nickel to 1.45 of copper. The Stobie mine is a much

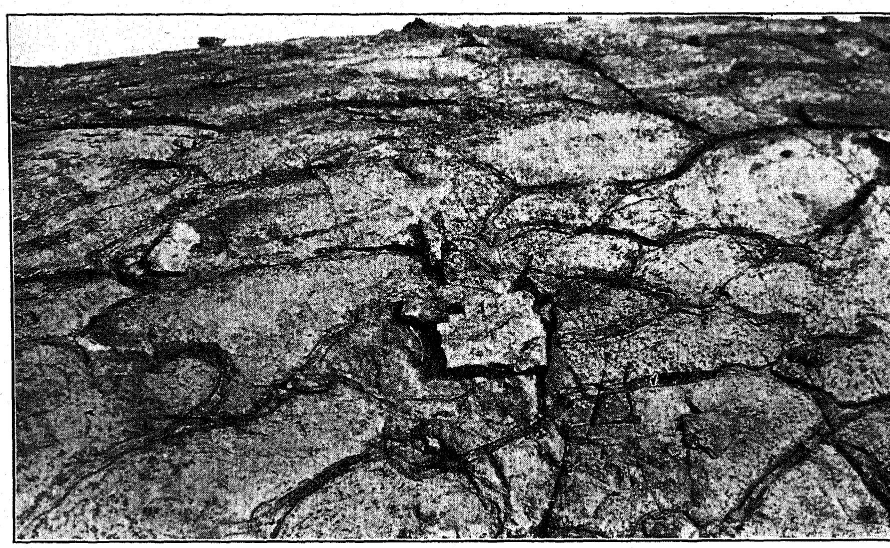

Fig. 59—Pillow lava, known as sudburite, Elsie mine, Sudbury area, Ontario. A. P. Coleman.

smaller deposit, and, although it was at one time a relatively important producer, 418,991 tons having been mined, it has not been worked since 1901. The Stobie ore contained 2.05 per cent. of nickel and 1.53 per cent. of copper.[1]

The rocks at the Frood-Stobie ore bodies may be grouped in the following manner, the oldest being shown at the bottom of the column and the youngest at the top.

Table Showing Rocks at Frood and Stobie Mines.

Granite.
Norite.
Gabbro.
Greenstone, including diorite.
Greywacké and quartzite.

[1] The Nickel Industry, 1913, p. 77.

The most ancient formation consists of schistose greywackés and quartzites belonging to the Timiskaming series. These sediments were intruded, more or less parallel to the bedding planes, by dikes, and other masses, of greenstones and diorite. The diorite is probably younger than the greenstone, the latter being more altered. In places the diorite is heavily mineralized, and it constitutes part of the ore body at the Frood. It was especially studied by Howe under the microscope who named the rock diorite.[1] Other writers have called it norite.[2] It consists of plagioclase, quartz, hornblende, biotite, magnetite, and apatite. It is a metamorphosed rock, the minerals of which have been re-crystallized. The greenstone and diorite have not been separated on the accompanying map, Fig. 60.

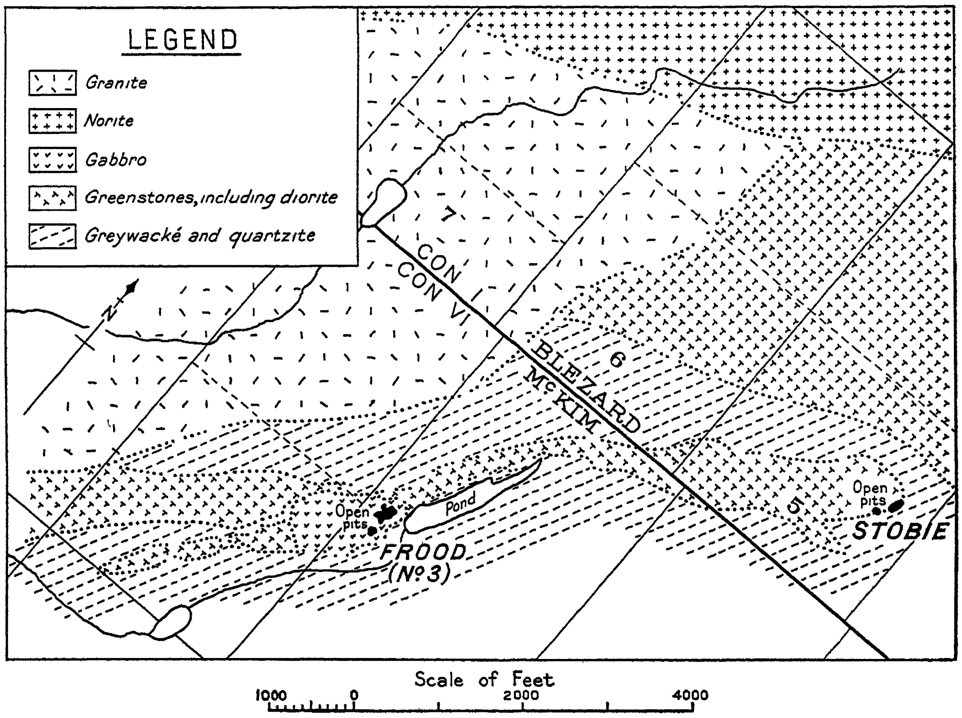

Fig. 60—Geological map of Frood and Stobie mines. After A. P. Coleman.

Following the diorite there were erupted masses of gabbro. An oval-shaped area, and the largest, of this rock occurs at the Frood mine. It has a width of about 800 feet and a length of about 1,200 feet, Fig. 60. In describing the rock Coleman refers to it as an "older" gabbro and considers that it may be an earlier effusion from the norite-micropegmatite magma. Near the Stobie there are also areas of a medium-grained gabbro, the outlines of which are difficult to determine on account of the gossan and drift, and the rock is therefore not shown on the map, Fig. 60. It outcrops 50 feet or more to the west of the Stobie ore body, and irregular masses extend for a few hundred feet to the west.

[1] Economic Geology, Vol. IX, September, 1914, p. 508.
[2] The Nickel Industry, Dept. of Mines, Canada.

The rocks mentioned above; *i.e.*, greywackés, quartzites, greenstones, diorite and gabbros, are the only ones with which the Frood and Stobie ore bodies are associated. Other rocks occur nearby. Norite, for instance, is found about a mile to the northwest. It is believed that it was erupted later than were any of the rocks at Frood and Stobie mines. The reason for this belief is that similar

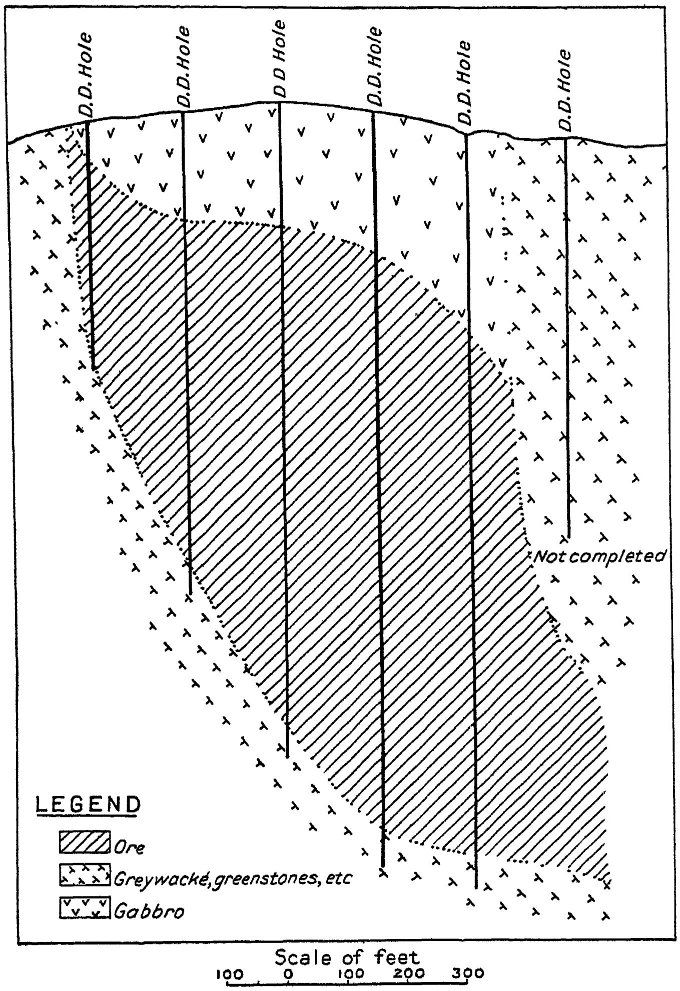

Fig. 61—Cross-section D.D. through Frood ore body, Sudbury area, Ontario.[1]

greenstones and gabbros occur along the edge of the norite at the Murray and Mount Nickel mines where they are seen to be older than the norite since the latter has caught up fragments of the greenstones and gabbros.

Between the Frood mine and the norite intrusive to the northwest a mass of what has been called "later" granite occurs. It sends dikes into the greenstones, gabbros and norite at Murray mine, and it is therefore younger than these rocks.

[1] The Nickel Industry, 1913.

The Frood and Stobie ore bodies may be described under one heading since they occur along a more or less continuous zone of mineralization, which has a length of about two miles and a maximum width of 900 feet. This zone of mineralization strikes northeast and southwest and dips steeply to the northwest, or roughly parallel to the strike and dip of the bedding planes of the greywacké and quartzite. It follows the path of dikes or irregular intrusions of the greenstones, diorite and gabbros referred to above, these rocks having been intruded more or less parallel to the bedding planes of the sediments. The Frood ore body occurs at the southwest end of the zone on a prominent ridge, and the Stobie at the northeast end. Between the two deposits there is more or less mineralization, but generally too low-grade to be of commercial value. Gabbros, greenstones, diorite, quartzites and greywackés are all mineralized, but most of the ore appears to occur in the diorite and gabbro at the Frood mine, while at the Stobie it occurs at the contact of greenstone and schistose greywackés or quartzites.

Fig. 62—"Spotted" diorite, actual size, Frood ore body, Sudbury area, Ontario. Black represents sulphides; white represents diorite. The sulphides replace or impregnate the rock.

The Frood, which has been called an offset deposit, dips in its upper part at an angle of about 65 degrees to the northwest. It is said to become flatter at depths of over 1,000 feet. The hill on which the deposit occurs is nearly all owned by the Canadian Copper Company. Part of the deposit, however, outcrops on the north half of lot 7 in the sixth concession of McKim township, and is owned by the Mond Nickel Company. Diamond drilling by this corporation has undoubtedly proved that the ore body continues into its property at depth. A shaft has been sunk to a depth of 1,005 feet to tap the deposit which is known as the Frood Extension. Operations, however, have been for the present (1916) suspended.

The character of the ore at Frood, in the old open pits, is in general like that of other ore bodies in the Sudbury area. These old pits were excavated in the gabbro. The latter has been fractured into blocks and fragments, round or angular in outline, and the sulphides fill the spaces between the gabbro fragments, cementing them together. "Spotted" gabbro also occurs. To the southwest and northeast of the oval-shaped gabbro mass the ore occurs largely in diorite, or

what has been described as norite by other writers. The ore in the heavily mineralized diorite is mostly of a different character from that which occurs in the gabbro. That is to say, sulphides are present in the diorite in "blebs" about the size of peas, giving the rock a striking "spotted" appearance, Fig. 62. Ore of this character appears to constitute a large part of the deposit; it cannot be hand-picked, and therefore some form of grinding and mechanical separation will have to be undertaken if it is desired to remove the rocky material. It may be added that some brecciation has also taken place in this diorite, producing ore similar to that occurring in the gabbro; *i.e.*, rock fragments of various shapes and sizes cemented together by massive sulphides. In the deeper levels of the mine there is much massive ore.

The gossan-covered surface at Frood is the largest in the Sudbury area.

The Stobie ore body is said to dip at an angle of 65 degrees toward the west, and it has been worked to a depth of 250 feet partly by two open pits. The deposit occurs at the contact of greenstones on the one hand and greywackés and quartzites on the other. The latter form the footwall and have been altered for 100 feet from the ore body to dark greenish grey schists. The greenstones are basic, medium to coarse-grained rocks, consisting largely of dark-coloured minerals, mainly hornblende; they are much metamorphosed and have probably been entirely re-crystallized. The ore is the usual variety found in the Sudbury area. It consists of angular or round fragments of greenstone, greywacké, and quartzite cemented together by sulphides. It is evident that the rocks were broken or crushed into crush-breccias and crush-conglomerates, and that the sulphides were then introduced so that they cemented the rock fragments together. In addition to this commercial ore body, the rocks—greenstone, gabbro, greywacké, and quartzite—to the west are more or less impregnated with sulphides, the gossan, or stained surface, having a length of 1,000 feet and a width of some 500 feet.

The origin of the Frood and Stobie deposits, and the more or less continuous zone of mineralization between the two mines may now be briefly discussed. The rocks at and between the two ore bodies have been crushed, brecciated, sheared and otherwise greatly disturbed. Crush-breccias and crush-conglomerates have been formed more or less continuously along the entire zone. All the rocks, whether they are gabbros, greenstones, greywackés or quartzites, have been subjected to this crushing and brecciation. Such a zone formed an ideal channel for the circulation of mineral-bearing solutions, and it seems reasonable to suppose that the sulphides were carried into their present positions by means of hot circulating waters. It is a fact that not only the diorites, gabbros and greenstones are "spotted" with blebs of ore, but also the quartzites and greywackés. It has been thought by some writers that the blebs of sulphides in the igneous rocks constitute proof that the sulphides cooled and crystallized out of the molten rock. Since, however, it is now known that these isolated blebs of sulphides occur also in sedimentary rocks like greywackés and quartzite, it is evident that this reasoning loses its force.

E. Howe has described in greater detail than any other writer the microscopic characters of the rocks at the Frood mine. He concluded that, although the appearance of the Frood rock to the eye suggested that the sulphides and silicates

formed contemporaneously, it nevertheless appeared to him that the magmatic origin of the sulphides could neither be proved nor disproved by a study of thin sections.[1]

Cameron and Little Stobie Ore Bodies

Between the Murray mine and Mount Nickel mine there are a number of small occurrences of ore, including the properties known as the Cameron and Little Stobie. There have been a dozen or more pits sunk at various places along this part of the area. Practically all of the ore exposed in these pits occurs in the greenstone, at a distance of a few feet to 150 feet from the norite. There is little mineralization in the latter rock. The test pits which constitute the Little Stobie mine occur on the north part of lot 6 in the first concession of Blezard township.

The Mount Nickel Ore Body

The Mount Nickel mine is situated on lot 5 in the second concession of Blezard township, about four miles north of the town of Sudbury. The deposit occurs at the contact of norite and greenstones or gabbro.

The oldest rocks in the vicinity of the mine are greenstones, all of them basic, but presenting at the same time a variety of textures from fine-grained to coarse-grained. The most common rock is a fine-grained greenstone, which is characterized by an amazing number of hornblende stringers, fractions of an inch in width, which ramify through the rock in all directions. This rock has been named sudburite by Coleman. Between Mount Nickel mine and the Blezard there is a belt of medium-grained gabbro, having a width of two or three hundred feet down to a few feet. It somewhat resembles the norite, but has a green colour. This gabbro is older than the norite, since the latter has caught up fragments of the gabbro. In addition to these two types—gabbro and fine-grained greenstone—there is a coarse-grained greenstone, of a very basic nature which consists largely of hornblende or pyroxene. It occurs between Mount Nickel and Stobie mines. The age relations of these three types of rock, one to another, are obscure. Whatever their age relations may be, it is certain that the norite is a younger rock than any of the other three.

The ore body has been worked by an open pit, which is about 150 feet long and from 25 to 75 feet wide. A shaft has been sunk to a depth of 165 feet. The ore body, as shown by diamond-drilling, is said to dip at an angle of about 30 degrees to the north.

The commercial part of the deposit occurs wholly in the footwall which consists of greenstone. The norite is found from a few feet to 100 feet to the north, and shows little mineralization.

The nature of the Mount Nickel ore body does not differ from that of the other deposits in the Sudbury area. The greenstone and gabbro have been brecciated into round or angular fragments, and the sulphides fill the spaces between the fragments, cementing them together. The ore contains 2.4 per cent. of nickel and 1.2 per cent. of copper.

The property was worked last in the year 1915 and the ore sold to the Mond Nickel Company.

[1] Economic Geology, Vol. IX, September, 1914, pp. 513-514.

The Sheppard Ore Body

The Sheppard mine is on the south half of lot 1 in the third concession of Blezard township. The deposit is near the contact of the norite and the adjacent greenstone, but the ore is largely in the greenstone. The shaft, which is said to be 110 feet deep, and from which two drifts run, is in the greenstone and about 75 feet south of the edge of the norite. In addition to the shaft there are five small pits, three of which are in the greenstone, a fourth exactly at the contact, and a fifth in the norite, 15 feet to the north. At the latter pit the norite is "spotted" with blebs of sulphides, some of the blebs being arranged in parallel lines which are roughly parallel to the contact. A small quantity of ore, over 125 tons, was shipped from this property.

To the east of the Sheppard mine, on lot 10 in the third concession of Garson township, some ore occurs and a test pit has been sunk.

The Kirkwood Ore Body

The Kirkwood mine is on lot 8 in the third concession of Garson township, about a mile and three-quarters west of the Garson mine. It was last worked in 1915 by the Mond Nickel Company, the ore being carried by an aerial tramway to the Garson mine.

The deposit occurs near the contact of greenstone and the norite, both of which rocks have been sheared and metamorphosed to schists and gneiss.

The norite has been more or less altered to schist or gneiss for two or three hundred feet north of its contact with the greenstone. It is, indeed, so much metamorphosed that it little resembles the same rock a few miles to the west, at Blezard or Murray mines, for instance. The schistosity of the greenstones and norite has a more or less vertical dip.

The ore bodies occur in the greenstones, about 100 feet south of the norite. The deposit is vertical, parallel to the dip of the schists. The workings are 200 feet deep and some of the stopes are 40 feet in width. The deposit is vein-like at times. Pure sulphides are often found resting sharply against the schistose greenstone. The ore, as usual, contains many inclusions of rock.

About half a mile southeast of the Kirkwood, on the northeast corner of lot 7 in the second concession of Garson township, a shaft, said to be 60 feet deep, has been sunk. This property is sometimes called the McConnell mine.

THE EASTERN NICKEL RANGE

The ore bodies on the eastern nickel range are of the marginal class, occurring at or near the basic edge of the norite-micropegmatite. Like other marginal deposits the ore occurs largely in the rocks adjacent to the norite, only a relatively small quantity being found in the latter rock. The rocks adjacent to the norite are greenstones, in which dikes or irregular intrusions of granite often occur. The character of the ore is similar to the commercial ore elsewhere in the Sudbury area, that is to say, it consists largely of angular or round fragments of rock cemented together by sulphides. "Spotted" rocks are also of common occurrence.

Beginning at the southeast corner of the range, ore is found near the line between concessions four and five, lot 7, in the township of Falconbridge, and elsewhere on this lot; exploration by stripping, by the sinking of a small shaft and by diamond drilling has been carried on. The drill holes show that the ore extends vertically downward for 800 feet in at least one place. If the dip of the contact of the norite follows the ore, then the norite contact will also have a more or less vertical dip like that at Kirkwood, Garson, and the Longyear properties east of Garson mine, on lot 10 in the fourth concession of Falconbridge.

Three miles north of the ore bodies referred to in the preceding paragraph there is a deposit on Boland's claims, mainly on lot 8 in the second concession of Maclennan township. The ore body appears to be at some distance east of the norite, and it occurs in greenstone, with green schist enclosing a little arkose or quartzite.

About a mile to the northwest of Boland's claims there are the properties known as W D 4, W D 6, W D 3, F 8, F 7, F 6, F 5, and W D 7, all in Maclennan township. A number of large test pits and small shafts have been sunk on F 7 and F 6, and in some of them more or less massive ore occurs having a width of 5 or 6 feet. The zone of mineralization on these two claims has a length of 760 feet in a straight line, and a width of 200 feet in places. On F 5 several pits and a small shaft have been sunk. Beyond this, on a steep hill, rising from the shore of Blue lake, there are two deposits on W D 1, the larger of which is 75 feet long and 35 feet wide. Diamond drilling has been done here; this claim, W D 1, is called the Victor.

On the east shore of Clear lake, which is just to the northwest of Blue lake, in the township of Capreol, there are strippings and small pits disclosing ore on claims W 2 and W 3. Some diamond drilling has been done.

On the east side of Ella lake, on W R 10, which is partly in Capreol and partly in Norman townships, a large test pit has been sunk showing ore. Between this claim and the Whistle mine there is some mineralization of the rocks.

THE NORTHERN NICKEL RANGE

On the northern nickel range there are four main ore bodies, namely, the Whistle, Big Levack, Strathcona and Levack. In the year 1916 only the Levack mine was being operated.

The commercial ore bodies of the marginal type, like those in other parts of the Sudbury nickel area, occur almost wholly in the rocks adjacent to the norite, not in the norite itself. There is, however, some light mineralization in that rock. With the exception of the Foy offset, and what is described as a small offset on Mosquito and Ministique lakes in the township of Cascaden, the ore bodies on the northern nickel range are all of the marginal type.

The Whistle Ore Body

The Whistle mine is situated 29 miles by rail northeast of Sudbury, mainly on lot 6 in the fourth concession of Norman township The mine is connected by a four-mile branch with the main line of the Canadian Northern railway. It is about at the junction of the eastern and northern nickel ranges.

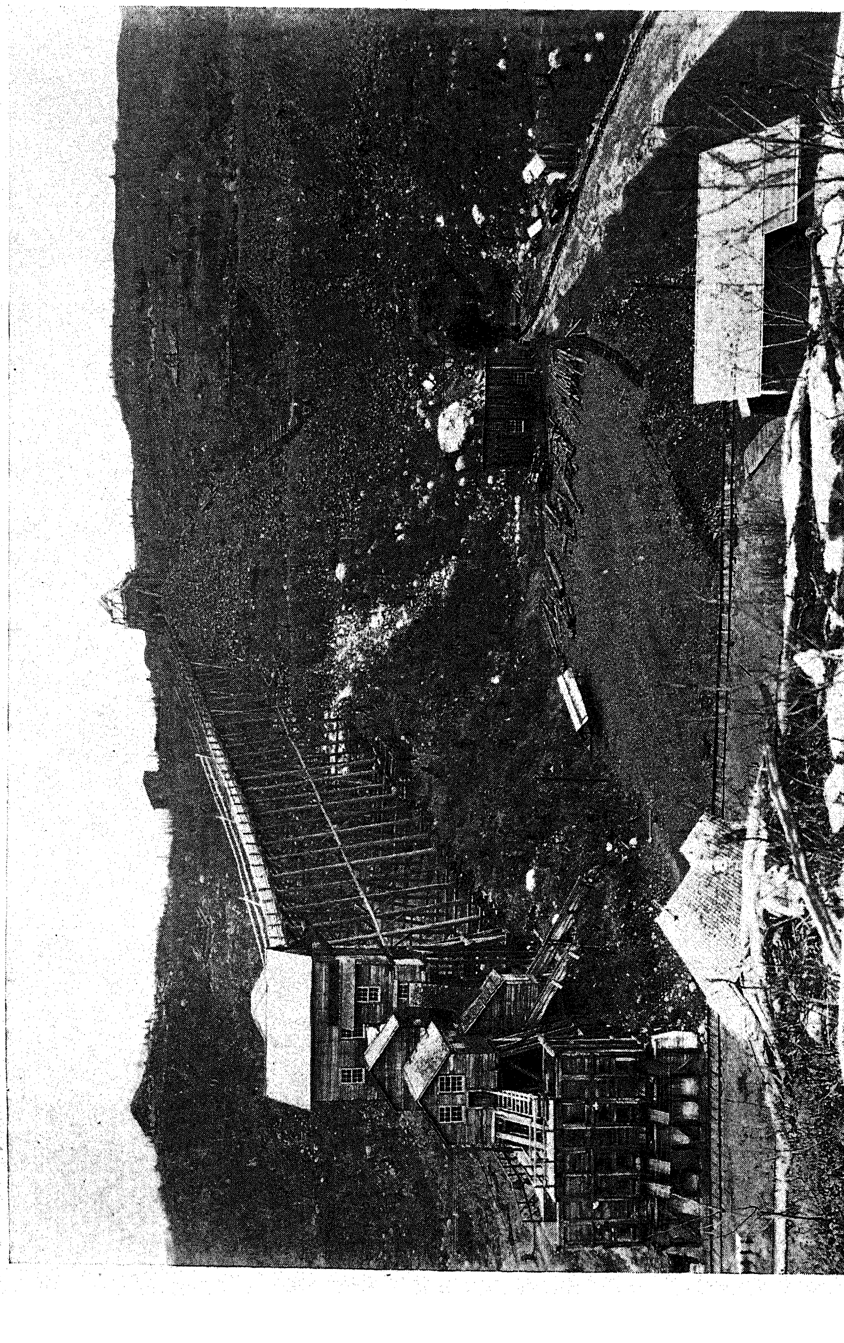

Fig. 63—Whistle mine, Sudbury area, Ontario, November 2nd, 1916.

The deposit occurs on the side and top of a prominent hill. The oldest rocks in the vicinity of the ore body are greenstones, fine, medium or coarse in grain. They sometimes have the texture of diabase, while at other times they have the appearance of diorite or gabbro. The greenstones are intersected by granite dikes, and in places are literally cut to pieces by that rock, Fig. 65. Banded gneiss has sometimes been formed by the injection of parallel veinlets of granite through the greenstone. This complex of greenstone and granite was intruded by the norite which is here a light, grey-coloured rock, having the composition shown in the table on page 119. The norite has been found in contact with the greenstone complex in several places, and wherever seen the contact is sharply defined. There is no transition between one rock and the other. The norite has caught up fragments of the greenstone.

The mineralized zone, along which the Whistle ore body occurs, is about one-third of a mile long, and a maximum of 1,000 feet wide. To the east and west

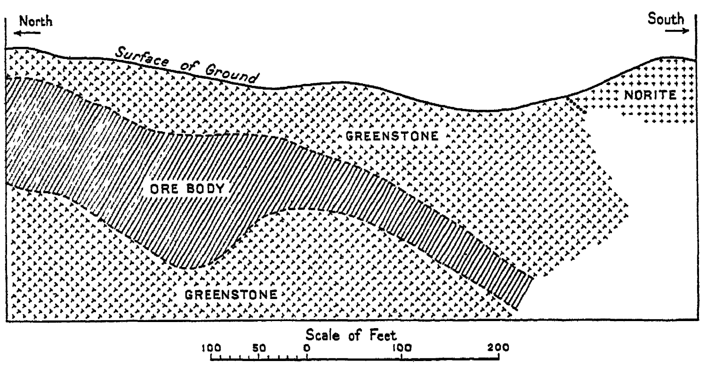

Fig. 64—Cross-section through Whistle ore body, Sudbury area, Ontario, showing how ore body occurs in greenstone

there are smaller mineralized areas. The commercial part of the main mineralized zone is of an irregular nature; pay ore occurs in "kidneys" in an erratic manner through the rocks. The ore consists of angular and round fragments of greenstone, and to a minor extent of granite fragments, cemented by sulphides. There is, in addition, much sulphide disseminated through the greenstone, and some sulphide occurs in irregular, small veinlets. "Spotted" greenstone is of common occurrence.

The ore body occurs wholly in the greenstone-granite complex, Fig. 64. In fact, with the exception of a few square yards of impregnated norite, the entire mineralized zone, is found in the greenstone-granite complex. The mineralization as seen on the surface may extend at times for 1,000 feet from the edge of the norite into the greenstone-granite complex. Sometimes mineralization comes up to the norite and ceases at that point. At other times it does not extend to within hundreds of feet of the norite. As far as surface exposures are concerned, it may be said that little or no commercial ore extends up to the norite.

The mine workings are all in the greenstone complex, so that no information from this source exists which throws any light on the angle of dip of the contact of the norite with the greenstones. Although diamond drilling has been carried on extensively, it was done in the greenstone, and so does not show the dip of the norite contact. If, however, it has a gentle dip to the southward, the probability is that vertical diamond-drill holes to the south of the greenstone, beginning in the norite, would disclose the continuation of the ore body dipping below the norite. An enormous quantity of unexplored ore probably exists at this property.

Fig. 65—Granite dikes intersecting greenstone, Whistle mine, Sudbury area, Ontario.

Some information regarding the dip of the norite may be gained by tracing the line of contact from the mine to the main line of the Canadian Northern railway, four miles to the west. On various hills a prominent set of jointing planes in the norite dips to the northward at angles of about 45 degree more or less. If these jointing planes are at right angles to the plane of contact of the norite with the underlying rocks, then the norite contact must dip to the southward at 45 degrees more or less.

The Whistle ore body is much like the Levack, Strathcona, and Big Levack deposits; in these occurrences the commercial ore is found in the rocks adjacent to the norite, not in the latter rock. At the Whistle the ore is mainly in greenstone, while at the other three deposits it is mainly in granite-gneiss.

Norman, Wisner, Bowell and Morgan Townships

Between the Whistle and the main line of the Canadian Northern railway, four miles to the west, there are a number of mineralized areas in Norman township in which small pits and shafts have been sunk. To the west of the railway about four miles, on location W D 16 in Wisner township, test pits and diamond drill cores demonstrate the presence of a considerable quantity of ore. On W D 13 and W D 15 in the same township ore also occurs. Test pits have been sunk on the former claim.

In the next township to the west, namely, Bowell, ore occurs on locations W D 13, W D 208, W D 35, W D 150 and W D 155. On the last named location test pits have been sunk and diamond drilling done. What has been called the Foy offset begins on W D 155, the offset having a width of 20 to 500 feet. It runs to the westward for six miles, and is described as "fairly continuous." It is mineralized here and there, and is thought to be a dike from the norite-micropegmatite, though difficulty may be met with in distinguishing it from other basic rocks associated with the granite. There is an ore body at the west end of the offset, on location W R 5, known as the Ross mine, in Foy township. The ore from this mine is reported to contain 2.75 per cent. of nickel. In the southwest part of Bowell township, on locations W D 238, W D 37, W D 231, W D 241, W D 251, ore has been disclosed by strippings and test pits.

Save for two patches of gossan at the northeast corner of Morgan township there is said to be neither gossan nor ore in this township.

Strathcona and Big Levack Ore Body

The names Strathcona and Big Levack have been applied to a single deposit, the former name being given to the west part and the latter to the east part. The ore body is located about 3½ miles northeast of the Levack, on lots 2 and 3 in the fourth concession of Levack township. An old waggon road connects the two properties.

The geology is similar to that at the Levack mine. The deposit, which has been called a marginal one, occurs at the contact of norite and granite-gneiss, the latter being identical to that found at Levack. The contact of granite-gneiss and norite is exposed a short distance west of the small lake; it is seen that the norite comes sharply against the granite-gneiss footwall without a transition zone, and that the contact dips about 45° to the southeast. The dip is shown in a cliff which cuts across the norite contact at right angles.

The mineralized zone has a length of half a mile, more or less, and a width of as much as 700 to 800 feet at the widest point. The ore lies almost wholly in the granite-gneiss. At the southwest end the ore is mainly in the granite-gneiss, though a little mineralization occurs in the norite. Towards the northeast, however, the ore body is entirely in the granite-gneiss. In places it is nearly a quarter of a mile from the norite.

The mineralization appears to be very irregularly distributed. Its character is seen particularly well on the side of a cliff. Here barren masses of granite-gneiss, 5 to 30 feet long, are surrounded by mineralized portions of the same rock. It is evident that the rock has been brecciated and shattered, and that the sulphides

have been deposited in the cracks. At the west end a mineralized zone, about 7 feet wide, extends into the norite about 100 feet, at right angles to the norite-gneiss contact. It is evident that this mineralized zone in the norite, like the entire deposit, was formed by solutions circulating along a weak or crushed zone in this rock.

There are two shafts on the Strathcona, having a depth of 45 and 30 feet respectively. The deposit has been diamond-drilled.

Levack, Cascaden and Trill Townships

The Levack, Strathcona and Big Levack ore bodies all occur in the township of Levack. In addition to these deposits there are found in Levack township a few other mineralized areas. A pit above five feet deep has been sunk 300 yards northeast of the small lake at the north end of lot 5 in the third concession of this township. On the hillside to the west of the southern end of the lake some stripping has been done. There is another small lake at the northeast corner of lot 6, in the second concession of Levack township. At the south end of this lake some mineralization occurs in the granite-gneiss, and it would appear that the area covered by the lake is likely to contain ore bodies.

The gossan at the last mentioned lake continues to the southwest for a few hundred yards to a deposit known as the Little Levack. The latter is half a mile northeast of the Levack mine. The workings of the Little Levack consist of an open pit, 30 or 40 feet wide and 100 feet long. The ore occurs in granite-gneiss in the form of veinlets, in irregular masses and in disseminated grains. The pit is on the side of a hill near the base, and the norite is exposed across the drift-covered valley 150 feet to the southeast.

At the south end of Cascaden township some mineralization occurs on the west shore of Mosquito lake, on lot 8 in the first concession of the township. Ore is also said to occur on the shore of a long southeastern arm of Ministique lake, immediately west of Mosquito lake.

In the township of Trill there is a hillside about a quarter of a mile south of the fifth concession on the line between lots 10 and 11. Ore is found on the south side of the hill and some test pits have been put down.

At the Trillabelle mine ore occurs in several places on a hill at the corner post between lots 10 and 11 on the line between concessions three and four. Pits and shafts have been sunk and some stripping done. The ore body occurs in greenstone.

A quarter of a mile southeast of the Trillabelle, a pit showing ore has been sunk, and 200 yards south of it there is another pit.

ORE BODIES NOT OF MARGINAL OR OFFSET TYPE, SUDBURY

There are a number of ore bodies in the Sudbury area which cannot be classed with the marginal or offset types. They occur neither in offsets nor at the contact of the main mass of the norite, but, on the contrary, are found in the country rock, as distinguished from the norite, from a mile to 20 miles from the main mass of the norite. Occurrences of this class are met with in Drury, Lorne and Nairn townships to the southwest of the main nickel area. More remote

still are those found about 20 miles to the northwest of the northern nickel range, at the northwest corner of Moncrief township and the eastern part of Craig township. There are also deposits northeast of Lake Wanapitei which deserve mention. The locations of most of these occurrences, together with others, are shown on Bell's old map of the Sudbury area which accompanies his report in the annual volume of the Geological Survey of Canada for the year 1890-91. Beyond a few brief references to the deposits by Coleman[1], Bell[2], and Hoffman[3], little has been written concerning them. They appear to be of much less importance than the ore bodies which are found in the main nickel area.

COMPOSITION OF MINE WATERS AT SUDBURY

Most of the nickel mines in the Sudbury district were worked in the early days by open pits. Some were closed down and have not been worked for years. In the course of time these pits became filled with water. The water in the Stobie pit has a dark muddy brown colour, while that at the Elsie has a pale green tint, the green probably due to the presence of a solution of nickel. Samples of the waters were collected for quantitative analyses, to ascertain the amounts of nickel, copper and iron present. The Elsie, Blezard and Stobie mines were selected for the purpose, and the results of the analyses are given in the table below.

Table showing the number of grains per gallon, of nickel, copper and iron contained in the mine water in the open pits at the Elsie, Blezard and Stobie mines, Sudbury district, Ontario, Canada.

	1	2	3	4	5
Nickel	0.3208	0.9625	1.6917	1.69[4]	1.7108
Copper	None	None	0.5250	None	0.7583
Iron	Trace	0.5833	10.2086	9.6836	12.6587

1. Elsie mine, west pit, surface water.
2. Elsie mine, east pit, surface water.
3. Blezard mine, surface water.
4. Blezard mine, 12 feet below surface.
5. Stobie mine, surface water.

Four out of five of the samples were taken at, or within a few inches of, the surface of the water. Of the two samples from the Blezard, one, No. 4, was obtained 12 feet below the surface. No copper was found in the latter sample, whereas the surface water of this mine contained 0.5250 grains of copper per gallon.

[1] The Nickel Industry, Dept. of Mines, Canada, 1913, pp. 47-48, Ont. Bur. Mines, 1905, Vol. 14, Part III, p. 145.
[2] Geol. Sur. Can., 1890-91, Vol. 5, Part F, pp 52-53.
[3] Geol. Sur. Can., 1890-91, Part R, pp. 39-48.
[4] W. K. McNeill states that there was not sufficient solution in the sample to make a quantitative determination of the nickel; a qualitative test appeared to show that there was about as much nickel present as that contained in No. 3. All the samples of mine water referred to in the text were taken in the summer of 1915.

The analyses show in every case that nickel is always present in the water, and that there is more of this element than copper in solution. This corresponds with the relative percentages of nickel and copper in the ore at the Stobie and Blezard; *i.e.*, there is more nickel than copper in the ore at these two mines.

It is interesting to calculate the total amount of nickel and copper which is present in the mine water of the Stobie. Of course it is impossible to estimate the volume of water in the mine without the assistance of the old mine plans, but if it be assumed that the workings have a volume equal to a rectangular prism 200 feet long by 100 feet wide by 100 feet deep, then the total nickel content amounts to 3,660 pounds, and the copper to 1,621 pounds.

LITERATURE ON SUDBURY GEOLOGY

It is felt that the present report on the geology of the Sudbury nickel-copper area is not the proper place in which to discuss the numerous papers and memoirs which have been published. Any reader desiring to peruse the literature will find a list of the works in the bibliography published in this volume. However, a few words may not be out of place respecting this matter.

If the literature relating to the geology of the area be studied it will be found that three workers stand out conspicuously from the others. These men are Robert Bell, A. E. Barlow and A. P. Coleman. Of Robert Bell it may be said that he outlined the foundation on which later geologists based their work. He succeeded in subdividing the rocks into their main groups; *i.e.*, (1) Grenville series, (2) Huronian series [Timiskaming], and (3) Upper Huronian series [Animikie]. These three principal subdivisions have remained substantially correct to the present day. In the course of his work Bell outlined, in the central part of the area, the "distinct geological basin," the delineation of which has proved of importance, for it was near its borders that most of the economic nickel-copper ore bodies have been discovered. More credit is due to Bell for the recognition and mapping of the Sudbury basin than is generally vouchsafed to him. He appreciated the significance of this well-defined geological feature and referred to its importance.[1]

While A. E. Barlow wrote an important report[2] on the Sudbury area, the maps which accompanied that report were also of great importance. Barlow had few, if any, equals in Canada as a geological map-maker.

Of all the reports which have appeared from time to time on the geology of the Sudbury area it may be said that those of A. P. Coleman have been of more assistance than have those of any other worker. In the preparation of the present Report for the Ontario Nickel Commission the writer wishes to particularly acknowledge his indebtedness to Coleman's works. This author's final report[3] has been freely drawn on, especially in describing the ore bodies on the eastern and northern nickel ranges.

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[1] Geol. Sur. Can., Vol. 5, 1890-91, Part F, p. 12.
[2] Ibid. Vol. 14, Part H. 1904, reprinted in 1907.
[3] The Nickel Industry, 1913, Dept. of Mines, Canada.

The above brief references to the work of geologists who have studied the Sudbury deposits would not be complete without mention of T. L. Walker and Chas. W. Dickson. Walker was the first geologist to discover that magmatic differentiation had taken place in the norite-micropegmatite. In respect of Dickson's work, which was published in 1903, it may be pointed out that he urged in a more convincing manner than any previous worker that the nickel-copper ores were deposited from hot circulating waters, and that the ores replace the norite.[1]

[1] While the Report of the Ontario Nickel Commission was going through the press an important publication by C. F. Tolman, Jr., and Austin F. Rogers was received. These authors have substantiated, by laboratory work, Dickson's main contention; namely, that the ores replace the norite. Their paper is entitled: "A Study of the Magmatic Sulphide Ores"; Leland Stanford Junior University Publications, University Series, 1916. A brief summary of their Report is given in the foot-note on page 133.

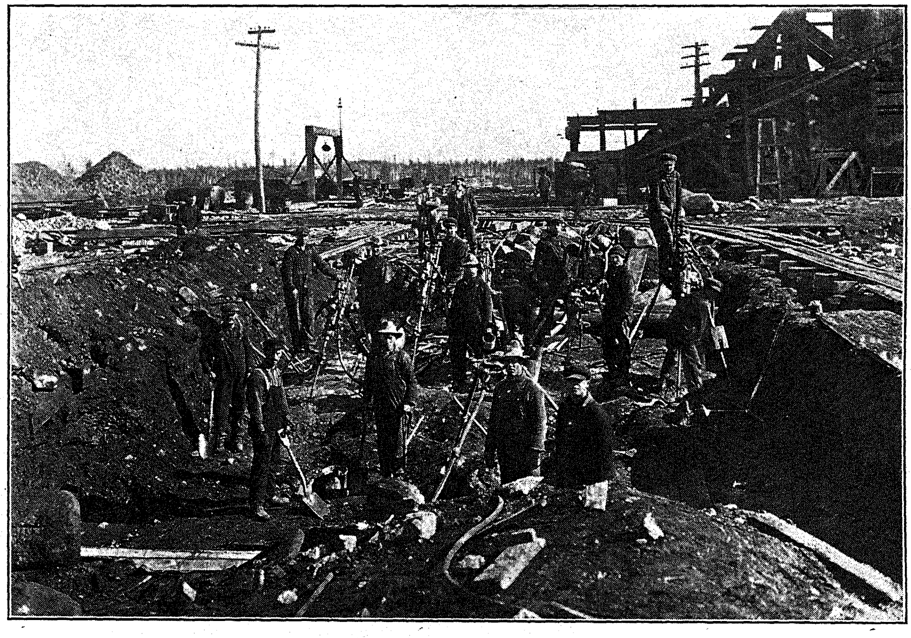


Fig. 66—Commencement of No. 3 shaft, 5 compartments, Creighton mine, 1915.

METHODS OF MINING IN SUDBURY AREA*

The ore bodies of the Sudbury district vary greatly in size, dip and configuration, and the methods of mining are dependent on these factors. The ores are essentially pyrrhotite, chalcopyrite and pentlandite. The enclosing rocks are hard, like the ore bodies, and but little timbering is required. They comprise norite, greenstones, quartzites, greywackés and granites. The ore bodies dip at angles of from 36 degrees to 90 degrees.

The problem of extracting the ore after the size and configuration of the ore body is known is a simple one owing to the nature of the ores and the enclosing rocks. Elaborate systems of timbering, caving, slicing or filling do not have to be considered. Where large stopes are to be worked out, pillars are left, and the backs are kept arched while the ore is being removed. Afterwards the pillars are robbed.

Ore was first mined in the Sudbury district by the open-pit method. The surface material was stripped off; the gossan, and overburden, the latter averaging up to ten feet in depth, was removed, and the open-pit method of mining followed. The ore was handled by derricks at first. Later a shaft was sunk adjacent to the open pit in the footwall, and connections were made with the open-pit at different levels. The ore was trammed to the shaft and dumped directly into skips. By this method about 3,000,000 tons were taken from the Creighton. Properties mined by this method were the Evans, No. 2, No. 4, No. 5, No. 6, Frood, Stobie, Crean Hill, Kirkwood, North Star, Victoria, Blezard, Murray and Creighton. Of these the Creighton was the largest pit, being about 670 feet long, 180 feet wide, and 200 feet deep. As the Creighton ore body dips at an angle of about 45 degrees, it was necessary to remove a large tonnage of waste from the hanging-wall. When all the ore, that could economically and safely be mined by the open-pit method, was taken out, the shafts were sunk to lower levels and overhand methods of stoping were adopted, a floor being left below the open pit. Where the ore bodies were narrow, the drifts were timbered over and the ore broken on the timbers. In wide ore bodies, dry-wall drifts were used and circular pillars left where necessary.

As the nickel industry grew, and increased tonnages were demanded, it became necessary to more thoroughly prospect the ore bodies and plan the work so that a constant large tonnage could be produced. The method of prospecting the ore bodies was by means of magnetic surveys and diamond drilling, the relative importance of these two methods being governed by local conditions at each property. In general it may be said that the magnetic survey serves only as an aid in locating an ore body. The prospecting is done by means of diamond drilling. Properties thoroughly drilled were the Frood and Creighton, of the Canadian Copper Company, the Levack, of the Mond Nickel Company, and the Murray, of the British America Nickel Corporation. In the latter property, for instance, the

* The Commissioners are indebted to Mr. T. F. Sutherland, Chief Inspector of Mines for Ontario, for the description of Mining Methods in the Sudbury Area, together with the notes on Power Plants, Mining Costs, and Workmen's Compensation.

surface was divided into 200-ft. squares, and a vertical hole drilled at the corners of the squares. By this means the dip, strike, configuration, assay and tonnage are pretty thoroughly known before any ore is removed. This information is sufficient to enable the whole operation of mining the ore to be planned in advance. Power plants, hoisting and sorting arrangements, shafts and equipment are all planned for the most economical handling of certain tonnages.

The magnetic surveys are made by the companies themselves. The diamond drilling is done under contract by drill companies located in Sudbury. The price varies from $2.75 to $4.00 a foot, depending on the location and size of contract.

CANADIAN COPPER COMPANY'S MINES

Crean Hill

The Crean Hill mine, situated in lot 5, concession 5, Denison township, has been developed to the 9th level at 830 feet by means of a 4-compartment shaft. This shaft is inclined at 57 degrees to the 5th level and at 71 degrees below this. A considerable tonnage was obtained from this property by the open-pit method of mining in the early days.

The present method of mining follows closely the system at the Creighton mine, described elsewhere, except that circular pillars are left instead of rib pillars. The ore body dips to the east at an angle of 60° and averages 2.9 per cent. of copper and 2.1 of nickel. By hand-picking from belts in the rock house about 50 per cent. of waste is removed. Up to the end of 1915, 660,000 tons of sorted ore had been shipped from this property. At the end of 1916, the ore reserves amounted to about 2,000,000' tons.

The equipment comprises the following: One Canadian Rand 1,600-cu. ft. compressor running at 120 r.p.m., with direct-connected motor drive. The cylinders are 25-in. diameter by 24-in. stroke and 16-in. diameter by 24-in. stroke. The motor is a 300-h.p., A.C.B. 3-phase 550-volt machine, at 125 r.p.m.

One Canadian Rand 2,500-cu. ft. machine, 2-stage, 17 inches and 28 inches by 24 inches with intercooler and aftercooler, driven by a 425-h.p. Canadian Westinghouse motor, 360 r.p.m., 550 volts, 3-phase, 25 cycles.

The hoist is a 3-drum motor-driven geared hoist built by the Denver Engineering works. The drums are 4-ft. 9-in. diameter and 4-ft. 10-in. wide. The hoisting speed is 500-ft. per minute. The motor is a 150-h.p. A.C.B., 500 r.p.m., 500 volts, 3-phase, 25 cycles.

Creighton

The Creighton mine is situated in lot 10, concession 1, Snider township, and lot 1, concession 1, Creighton township. The property was acquired by the Canadian Copper Company in 1890, but did not become a shipper until 1900. The ore averages 4.4 per cent. of nickel and 1.5 per cent. of copper. The production to the end of 1915 amounted to 4,611,577 tons. The ore body has a maximum length of about 1,000 feet, and has been proven to a depth of 2,000 feet measured along its dip, the present ore reserves amounting to about 10,000,000 tons. It dips to the west at an angle of about 45 degrees.

As mentioned before, a large tonnage was removed from this property by the open-pit method of mining, the ore being removed through a 3-compartment shaft sunk in the granite footwall at an angle of 59 degrees near the east end of the ore body. As the depth of workings increased, it became necessary to change from the open-pit method to underground mining.

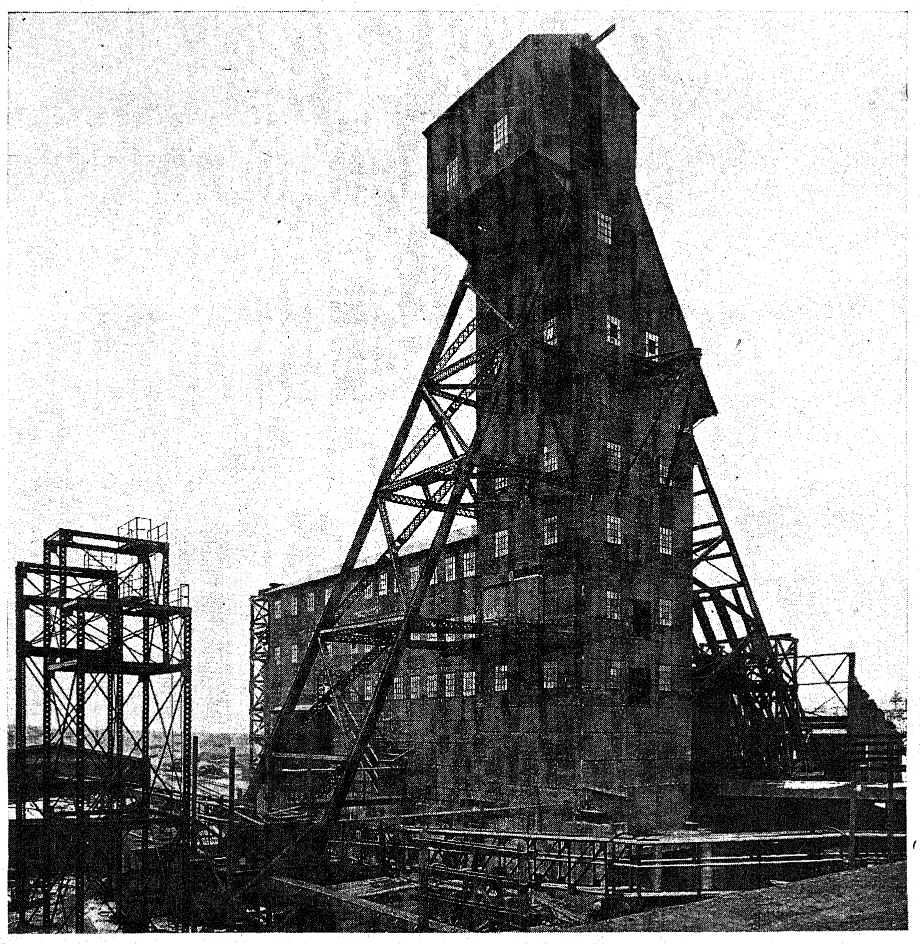
A second shaft was therefore sunk in the footwall. This was a 4-compartment shaft comprising a manway, two skipways and a compartment for handling men and material. This shaft was sunk near the westerly end of the open pit, and was carried to a depth of 830 feet on an angle of 47 degrees. On the 6th and 10th levels of this shaft a Farrel jaw crusher, with a 30-in. x 42-in. opening, crushing to 6 inches is installed. These crushers are each driven by two 100-h.p. motors and discharge into storage pockets holding approximately 400 tons. The ore from the storage pocket passes into a measuring pocket at the loading station about 60 feet below the haulage level. By this method the skip is loaded in about 10 seconds and the time for a return trip from the 6th level loading station, including loading, is 1¾ minutes. The skips, 5-ton capacity, are operated in balance, the hoisting speed being about 1,100 ft. per minute. On the main haulage levels 4½- and 5-ton storage-battery locomotives are used, hauling trains of four 56-cubic foot side-dumping steel cars, which are mechanically dumped at the crushers.

All the ore goes through these crushers, the ore from the upper level being passed down through ore-passes, which discharge into a crusher. Waste rock is handled through separate rock passes and storage pockets, which discharge into the skips 30 feet below the haulage levels.

A third shaft, known as No. 3, is being sunk in the footwall 145 feet southwest of No. 2. It dips at an angle of 55 degrees and is to be continued to the 16th level. This shaft measures 8 feet by 33 feet, and is divided into five compartments, which consist of a manway, two skip compartments, and two cage compartments. The shaft is concreted for a distance of 40 feet below the collar. The skip-track consists of 85-pound rails, resting on wall-plates, which in turn are supported on concrete piers. It is planned to place a crusher below the 14th level station with storage and measuring pockets of the same type as used in No. 2 shaft. Ore-passes will extend downward from the upper levels to this crusher. Skips of 8-ton capacity, hoisting in balance, are to be used. The hoist will have 12-foot drums and a rope speed of 2,500 feet per minute. Stations have been cut in this shaft at the 6th, 8th, 10th, 12th and 14th levels. The first three levels correspond with similarly numbered levels from No. 2 shaft. The distance between levels is 150 feet measured along the incline. Intermediate or sub-levels are to be driven halfway between these main levels in the footwall and will be numbered 7, 9, 11 and 13. These sub-levels are necessary to remove the broken ore from the footwall owing to the low angle at which the ore body lies.

The main level stations are 25 feet wide and are cut in the footwall. The main drifts are driven in the footwall parallel to the ore body. Levels Nos. 6, 10, 12 and 14 and motor-haulage levels are driven 10 feet wide and 9 feet high, laid with 40-lb. rails, and have ½ of 1 per cent. grade to the crusher station. The other levels are driven the ordinary size, 8 ft. by 8 ft., and are laid with 25-lb. rails, with a grade of 2/3 of 1 per cent. to the ore-passes which lead to the crusher on the

first haulage level below. Rib pillars, 15 feet wide, are left every 75 feet approximately at right angles to the strike of the ore body. In these rib pillars crosscuts are driven from the main levels to the hanging side of the ore body. These crosscuts are carried on a 2/3 of 1 per cent. grade. This gives a series of parallel stopes 60 feet wide traversing the ore body throughout its entire length. From each side of the crosscuts box holes are cut at 30-foot centres up into the stopes. As far as possible these box holes are staggered in the crosscuts and also as regards



Rock house at No. 3 shaft, Creighton mine.

the stope. The box holes are carried up about 15 feet, then chambered out and stoping commenced. A 15-foot floor is left in the bottom of each stope. The chutes are 4½ feet wide and are built of 12-in. by 12-in. timbers. They are lined with 6-in. by 6-in. or 6-in. by 8-in. timber, the bottom sloping at an angle of 25 degrees, and protected by a ½-in. steel plate. Formerly steel arc gates, air-operated, were used on the chutes, but these have been discarded and a stop log is now used.

In the stopes the shrinkage method of mining is followed. As soon as a stope is started manways are carried up along the footwall in the pillars and connected with the stopes every 25 feet. All pipe-lines, etc., are carried in these manways.

For development work 3⅛-in. piston drills are used, and for stoping both piston and Leyner drills are employed, 8-ft. to 10-ft. holes being the rule. Block holers follow the big machines in the stopes. The drills are supplied with air at a pressure of 90 pounds and 40 per cent. forcite is used for all blasting operations.

In the rock house the skips dump over grizzlies and the coarse material is fed through 18-in. by 30-in. jaw crushers, which discharge upon travelling picking belts, where about 17 per cent. of waste material is removed by hand-picking. The ore falls into ore bins, which discharge directly into railway cars beneath the rock house.

The equipment comprises the following: One Bellis and Morcom compressor, 2-stage, 42-in. and 25-in. by 21-in., 5,000-cubic foot capacity at 100 lbs. pressure and 187½ r p.m., driven by a 900 k.v.a., 3-phase, 2,400-volt, 187½ r.p.m. auto-synchronous motor with a 22 k.w. 25 to 35-volt direct-connected exciter.

One Canadian Rand 1,600-cubic foot machine running at 120 r.p.m. with direct-connected motor drive. The cylinders are 25-in. diameter by 24-in. stroke and 16-in. diameter by 24-in. stroke. The motor is a 300-h.p. A.C.B., 125 r.p.m., 3-phase, 550-volt, 25 cycles.

One Canadian Rand 2,500-cubic foot machine, 2-stage, 17 inches and 28 inches by 24 inches, with intercooler and aftercooler, driven by a 425-h.p. Canadian Westinghouse motor, 360 r.p.m., 550 volts, 3-phase, 25 cycles.

One Canadian Rand 2-stage compound 1,200-cubic foot machine, 12 inches and 20 inches by 18 inches, driven by a 200-h.p. Crocker Wheeler motor, 500 r.p.m., 550 volts, 3-phase, 25 cycles.

Hoisting through No. 1 shaft is done by a 2-drum hoist of the Denver Engineering Works, motor-driven. The drums are 4-ft. 9-in. by 4-ft. 10-in. wide, with friction band brake. The hoisting speed is 500 feet per minute. The motor is a 150-h.p. A.C.B., 500 r.p.m., 550 volts, 3-phase, 25 cycles.

At No. 2 shaft ore is hoisted by a double-drum electric hoist, built by the Nordberg Manufacturing Company. The drums are 7-ft. diameter and 4-ft. face, using a 1⅛-in. diameter rope. The hoist is equipped with parallel-motion post brakes operated by oil-thrust cylinders. The hoisting speed is 1,100 feet per minute with a 5-ton load of ore. The hoist is operated by a 350-h.p. 500-480 r.p.m., A.C.B., 25-cycle motor with limit switches positively geared to each drum.

The man-cage hoist at this shaft is one drum of a 3-drum hoist built by the Denver Engineering Works, driven by a 250-h.p., A.C.B., 500 r.p.m., 550 volts, 3-phase, 25-cycle motor, and equipped with both band and post brakes. The drum is 4-ft. 9-in. diameter by 4-ft. face. The hoisting speed is 690 feet per minute. At No. 3 shaft a Wellman Seaver Morgan Company double-drum electric hoist is in use temporarily during construction. The drums are 72-in. diameter by 48-in. face. The brake is a post brake air-operated. The hoisting speed is 800 feet per minute with a load of 11,700 lbs. The hoist is driven by an A.C.B., 250-h.p. motor 500-480 r.p.m., with limit switches and brake solenoids.

No. 2 Mine

No. 2 mine of the Canadian Copper Company is situated in the town of Copper Cliff. It was opened up in 1898 and operated until 1903. It was re-opened in 1911, and up to the end of 1915 had produced 656,000 tons of ore.

The mine has been developed by a 3-compartment shaft at an angle of 87 degrees. This shaft extends to the ninth level, a distance of 721 feet. Below this level a winze has been carried to the eleventh level, 360 feet deep.

The ore body is columnar in form, being nearly vertical, and averaging 230 feet in length by 115 in width. It averages 2.6 per cent. of nickel and 1.8 of copper. About 12 per cent. of waste is sorted out in the rock house.

The equipment comprises one Canadian Rand 1,600-cu. ft. compressor, running at 120 r.p.m., with direct-connected motor drive. The cylinders are 25-in. diameter by 24-in. stroke and 16-in. diameter by 24-in. stroke. Hoisting is done by a 2-drum motor-driven hoist built by the Denver Engineering works.

No. 3 Mine

The Frood, or No. 3 mine, lot 7, con. 6, McKim township, is the largest body of ore known in the Sudbury district. The original No. 3 mine lies a quarter of a mile northeast of the present workings, and was operated from 1899 to 1903, producing 110,545 tons of ore averaging 2.66 per cent. of nickel and 1.39 of copper.

The present ore body was thoroughly prospected by diamond drills, and about 45 million tons of ore proven, carrying 2 per cent. of nickel and 1½ of copper. Preparations were made to mine a large tonnage from this property, but developments at the Creighton mine were such that this property was closed down in 1914 after about 87,000 tons had been hoisted that year. The mine was being developed from two shafts,—No. 1, a 4-compartment shaft dipping at an angle of 77 degrees, 420 feet deep, and No. 2 shaft, a 3-compartment vertical shaft, 350 feet in depth. No. 2 shaft lies 625 feet northeast of No. 1. These shafts are connected by drifts on the 300-ft. level.

The method of mining used was to drive a main drift a short distance south of the ore body and following the general direction of the ore body on the south side. Crosscuts 50 feet apart were driven north from the main drift at right angles to it. Raises were put up in the crosscuts about 50 feet apart and placed alternately on either side of the drift. These raises were breasted out and joined at a height of 15 feet above the floor level, thus merging into a large stope. Pillars 25 feet in diameter were left to support the back, and the shrinkage method of mining was followed.

A railroad 5 miles in length was built by the company from Copper Cliff to the mine and a town laid out. Over 100 company houses were built. The town was incorporated under the name of Frood Mine.

Dill Quartz Quarry

Quartz for the smelter at Copper Cliff is obtained by the Canadian Copper Company from a quarry owned and operated by the company in Dill township.

This quarry is worked only during the summer, a sufficient supply of quartz being stock-piled at the smelter to carry the plant through the winter months.

The open-pit method of mining is followed, the pit now being about 55 feet in depth. The quartz is hoisted in small cars on an incline and dumped into a storage bin which discharges into railway cars.

MOND NICKEL COMPANY MINES

Frood Extension

The Frood Extension mine is situated in the north half of lot 7, concession 6, McKim township. The ore body is an extension of the Frood ore body of the Canadian Copper Company. On the outbreak of war development work at this property ceased, and the company hastened the development of the Levack mine.

A vertical 4-compartment shaft, 21-ft. by 7-ft., has been sunk to 1,005 feet.

On the first, or 400-ft. level, a drift runs southeast 230 feet. From the end of this drift a raise extends to the surface, and a winze has been sunk to a depth of 170 feet below the level.

On the second, or 750-ft. level, a drift runs southeast 220 feet. Near the end of this drift a raise was started to connect with the winze from the first level. A winze has also been started near the end of this drift, and is 70 feet deep.

On the third, or 900-ft. level, the station has been cut and 210 feet of drifting done southeast of the shaft.

About 500,000 tons of ore have been proven by diamond drilling containing about 2 per cent. of nickel and the same percentage of copper.

The power house has been completed and contains:—One Nordberg geared hoist, 23-in. and 23-in. by 48-in., with two drums, 10 feet in diameter with 78-in. faces. It is equipped for air but can be run by steam. Provision has been made whereby a third clutched drum for hoisting men may be added when desired.

There are one 2,800-cu. ft. Nordberg air compressor, and one 1,750-cu. ft. Rand air compressor, belt-driven.

The Garson Mine

The Garson mine, lots 4 and 5, concession 3, Garson township, up to the end of 1915 had produced 872,179 tons of ore averaging about 1.7 per cent. of copper and 2.4 of nickel. This has been the most important producer for the Mond Nickel Company. It is connected with the Canadian Northern railway by a spur, 3½ miles long. During 1915 the monthly production averaged about 18,000 tons of ore and quartz.

The main shaft is a vertical 3-compartment shaft, lined with 4-in. by 8-in. cribbing, and has been sunk to a depth of 870 feet. It is equipped with 3-ton skips hoisting in balance. At first the cars on each level were dumped directly into the skips, but later this was changed and the greater part of the ore is now lowered through raises to a chute below the fourth level leading to measuring pockets on the fifth level which load into the skips. Similar loading pockets are being put in on the seventh level to handle the ore stoped between the fourth and sixth levels.

The ore body is very irregular in form and may be said to comprise two main ore bodies, very erratic in character, and lying somewhat in the form of a

quadrant of a circle, as well as a number of smaller ore bodies which radiate out from the main ones. In the main the average contents of these veins are much alike, but one of the smaller bodies is very rich in copper, the ore sometimes running as high as 10 per cent. of copper. Pentlandite, in visible form, also occurs in some places. The ore bodies dip to the southeast at angles of from 50 to 60 degrees and the two main ore bodies intersect about the sixth level, forming a considerable enlargement. While not definitely known, it is believed that the ore body forks below the sixth level and continues down as separate bodies. No work has yet been done below the sixth level to verify this.

Each of the ore bodies has its own peculiarities and as these do not persist from level to level it has been hard to adopt any general mining system which will satisfy all conditions.

The ore has always been developed by means of drifts and then section-cutting in the ore till the body is outlined on that level. Afterwards the workable portion, as shown on the assay map, is mined, the poorer portions being left for pillars, if any are considered necessary. Above the fourth level the practice has been to build dry walls leaving, as first developed, chutes and later heavy timbered shovelling places, for handling the ore. A filled stope extends above the dry wall, leaving only a ten-foot floor between the back of the stope and the level above. From time to time, as the work below progresses, these floors are removed by underhand work. No timber has been used in the stopes and in general the ground stands remarkably well.

On a portion of the fourth level and below, the method has been changed to cutting mill holes out of the solid and leaving a portion of the back over these for protection of working place. Platforms slightly higher than the tram-cars are built below these openings, and from these the ore is shovelled into the cars.

On the footwall of one of the main ore bodies was a quartz vein carrying small values and running from 6 to 12 feet in width. This was mined separately and used as a flux in the company's smelter.

Hoisting is done by an Allis-Chalmers hoist with two 7-foot drums, and 6-foot faces, driven by a 250-h.p. motor.

Air for underground operation is supplied by 4 compressors, 3 of the Rand compound type, 1,800-cu. ft. capacity each, and one Ingersoll-Sargent 1,700-cu. ft. capacity. All are electrically driven.

Double transformer arrangements are provided for receiving 44,000 and 16,500 volts, the former being supplied by the company's plant at Wabageshik and the latter by current from the Wahnapitae Power Company.

Sorting arrangements in the shaft house follow the usual custom in the district. About 25 per cent. of waste is picked out on bumping tables.

Levack Mine

The Levack mine is situated in lots 6 and 7, concession 2, Levack township. Diamond drilling has proved the presence of a large body of ore near the contact of the norite and gneiss.

A branch railway, four miles long, leads to the mine from Levack station on the C.P.R. main line, 23 miles west of Sudbury, and 31 miles from the smelter at Coniston. This spur is owned by the mining company.

An electric transmission line, 28 miles long, delivers power, from the Wabageshik plant of the Lorne Power Company, to the mine at 44,000 volts

The power house at the mine has a brick exterior and cement Hyrib interior. It contains an 1,800-cu. ft. Rand compound duplex compressor, belt-driven by a 300-h.p. motor; a 3,200-cu. ft. Ingersoll-Rand Rogler-valve compressor, direct-driven by a 550-h.p. synchronous motor. In a separate building a 1,100-cu. ft. Rand, steam or electric, compressor, will serve as a reserve. Three General Electric water-cooled transformers are set up in a wing off the power house.

The hoist house is of the same type of construction as the power house. It contains an Allis-Chalmers hoist with two cylindrical drums, 7-ft. diameter and 6-ft. face. This hoist is capable of handling a 4-ton load in the skip, and is driven by a specially designed Allis-Chalmers motor of 250-h.p.

In the rock house considerable storage capacity is provided above two Hadfield jaw crushers. The latter have an opening of 18 inches by 24 inches, and are automatically fed by a short Stephens-Adamson pan conveyor from which coarse waste is picked. The crushed product is screened and the oversize sorted on belt conveyors. In all about 33 per cent. of waste is removed.

A 5-compartment shaft, pitching to the southeast at an angle of 65 degrees, was begun in April, 1914. A concrete collar extends to a depth of 12 feet, and from the bottom of the collar to 75 feet in depth concrete has been poured behind the timbers. This shaft was sunk in a fold of the footwall which extends well into the ore body. The first level was cut at 168 feet measured on the incline and subsequent levels at 100-ft. vertical intervals.

The general mode of attack is to drive a main drift north and south from the shaft through the centre of the ore body, which is then blocked out into 100-ft. stopes separated by 40-ft. rib pillars. From the main drift crosscuts are driven centrally through these pillars to the foot and hanging walls for exploratory work and manway connections. Two crosscuts are driven from the main drift under each stope for drawing the stopes. When this preliminary development is completed, a main haulage drift is driven from the shaft in the footwall connecting with the different crosscuts under the stope sections. By this means the empty cars from the shaft are brought in through the main drift, loaded in the crosscuts and returned to the shaft by the footwall drift.

Tramming is at present done in 2-ton cars dumping directly into the skips. Ultimately storage pockets will be cut out below certain levels.

Stoping will be done by slicing from the footwall to the hanging-wall, keeping the back of the stope at such an angle that only wet holes will be drilled. Both chutes and shovelling platforms are used.

This property has been thoroughly prospected by diamond drill and about 4½ million tons of ore proven, carrying about 1.5 per cent. of copper and 3.2 of nickel.

Victoria Mine

The Victoria mine, situated in lot 8, concession 4, Denison township, is the deepest mine in Ontario. The mine is situated on the Algoma Eastern Railroad, 34 miles west of Coniston. At the end of 1916 the 3-compartment vertical shaft was 2,618 feet deep. The ore occurs as two inclined columns about 169 feet apart, which dip uniformly to the southeast at 70 degrees.

Up to the end of 1915 this property has produced 619,612 tons of ore averaging about 1.6 per cent. of nickel and 3.3 of copper. The production during 1915 was at the rate of about 5,000 tons a month.

The vertical shaft was sunk between the two ore bodies and, owing to the dip of the ore, it has been found good practice at depth to run the levels at 300-ft. intervals. The method is to underhand-stope the upper 200 feet and overhand-stope the lower 100. The ore is hoisted on cages and the ordinary methods of crushing and picking are followed. About 25 per cent of waste is picked out.

The equipment comprises one 1,800-cu. ft. duplex 2-stage tandem Rand compressor driven by a 300-h.p. motor, and a Nordberg hoist with 10-ft. drums and 78-in. faces driven by a 400-h.p. Siemens motor capable of hoisting a 4-ton load from 4,000 feet. The hoist is equipped with the latest Welch safety devices, and has a hoisting speed of 1,000 feet per minute.

Worthington Mine

The Worthington mine, lot 2, concession 2, Drury township, was first operated in 1890, and up to the end of 1915 had produced 117,794 tons of ore. The property was re-opened in 1914 by the Mond Nickel Company. The mine is situated on the Soo branch of the Canadian Pacific railway, 34 miles west of Coniston.

The Worthington ore contains a little niccolite and considerable pentlandite. The picked ore as shipped averages about 3 per cent. of copper and 3.5 of nickel.

A 3-compartment shaft, dipping to the southeast at an angle of 80°, has been sunk to the 600-ft. level.

The ore body is unusual in that the rock content is greater than that of any of the other working mines of the district, and consequently closer attention has to be given to sorting in order to obtain a shipping product without too high a loss in the waste product. In the rock house the run of mine is dumped over grizzlies upon sorting platforms where a preliminary sorting is made, the ore and rock falling into separate bins. The rock and ore bins feed into separate 18-in. by 24-in. jaw crushers, crushing to a 2½-in. ring, which discharge upon bumping tables where the crushed material is washed and sorted by hand, the waste being discharged onto a travelling belt. The fines from the grizzly also pass over a bumping table, where waste is picked out and discharged onto this travelling belt. The travelling belt feeds an 18-in. by 24-in. jaw crusher, set at 1½ in., which discharges into railway cars, this crushed material being sold to the Canadian Pacific railway for ballast. About 60 per cent. of waste is sorted out by this treatment.

The power house contains an Allis-Chalmers hoist with two cylindrical drums 7-ft. diameter and 6-ft. face, driven by a 250-h.p. motor and capable of handling a 4-ton load in the skip. The compressor is a 2,100-cu. ft. compound Rand type driven by a 350-h.p. motor.

Bruce Mines

The Mond Nickel Company in 1915 bought the Bruce mines and commenced mining operations. The Bruce mines are situated in Plummer Additional township, on the Soo branch of the Canadian Pacific railway, 152 miles west of Coniston. The ore is quartz, contaning about 85 per cent. of silica, and about 6 of chalcopyrite. It is used as a flux at the company's smelter at Coniston. About 50,000 tons a year will be required for this purpose.

The Bruce mines were discovered in 1846, and opened up in 1849. Before being acquired by the present company the mines had been operated at various times and a total of about 250,000 tons of ore had been mined. The chief mine has been developed by a 3-compartment shaft to the 400-ft. level. The vein averages 5 feet in width and has been proven by underground workings for over 5,000 feet. The workings from the main shaft extend over 2,400 feet. The plant is operated by steam, coal being the fuel used.

POWER PLANTS

The Canadian Copper Company and the Mond Nickel Company operate their mines and smelters in the Sudbury district by hydro-electric power, the Canadian Copper Company obtaining their power from the Huronian Power Company, a subsidiary company, and the Mond Nickel Company from the Lorne Power Company, also a subsidiary company. There are power plants both on the Vermilion and Spanish rivers. The Mond Nickel Company also buy hydro-electric power from the Wahnapitae Power Company, which generates power on the Wanapitei river, and supplies the town of Sudbury, the Long Lake Gold mine, and the Whistle mine of the British America Nickel Corporation. The latter company is the successor to the Dominion Nickel-Copper Company. In general it may be said that hydro-electric power costs from $12 to $20 per horse power per year, depending on the capital expenditure and the cost of operation. The following is a description of the power plants:

Lorne Power Company

1. Nairn Falls Power Plant, Spanish River

The Nairn Falls power plant of the Lorne Power Company, Limited, is located on the Spanish river at Nairn Falls. The head developed is 30 feet, being the maximum obtainable at this point on the river. The dam is of reinforced concrete and rests on solid rock. It is designed to allow the maximum known flow of the river to pass through the dam without raising the head water of the river. The stop-logs for controlling the river are raised and lowered by an electrically operated stop-log winch.

The forebay is protected by steel trash racks. The power house is further protected by steel rack, supported by concrete and steel piers. The power house is designed for three vertical units. The vertical turbines develop about 2,300 h.p. and are set in reinforced concrete scroll chamber inside of speed rings. The draft tubes are concrete and reinforced with steel where required.

The vertical generators are directly coupled to the turbine shaft and develop 1,200-k.w. at 80 per cent. of power factor, 60-cycle at 100 r.p.m. The weight of runner, shaft and water thrust is taken by Kingsbury thrust bearings. Only two units are installed at the present time.

There are two exciters, one turbine-driven and one motor-driven, each large enough to furnish excitation for three main units. The hydraulic units are governed by Allis-Chalmers oil-pressure governors at 125-lb. pressure. The entire plant is lubricated from gravity oil tanks, and a complete system for filtering and storing oils is installed in the basement of the power house.

There are three water-cooled transformers, 1,600 k.v.a. capacity, 60-cycle, 3-phase, which take the current from the generators at 2,200 volts and deliver it to the transmission line at 44,000 volts. A 50-ton electric-operated crane travels above the main floor of the power house. The plant is fully protected by horn gap and electrolytic lightning arresters.

2. Wabageshik Power Plant

The Wabageshik power plant of the same company is situated on the Vermilion river at Wabageshik.

The main dam, forebay and power house are built of concrete on rock and are of heavy design and permanent construction.

The penstocks are 450 feet in length and 8 feet in diameter. They are provided wtih two expansion joints each and are supported on concrete piers. Steel head gates are provided, and stop-log checks have been constructed in the forebay with a 12-inch drain pipe to provide for examination of the head gates if this becomes necessary.

There are two units, each consisting of a horizontal twin turbine, 2,200 h.p., 300 r.p.m., built to operate under 50 feet head; direct-coupled alternator, 1,500 k.w. (or 1,200 k.w. at 80 per cent. power factor), 60-cycle; exciter turbine, 110 h.p., 875 r.p.m.; exciter generator, 60 k.w., 120 volts; Allis-Chalmers Company oil governor for both main and exciter turbines. The exciter-turbine penstocks are branched from the main penstocks, and are coupled together in such a manner that either exciter turbine may be operated from either main penstock. Similarly either exciter may be used with either alternator. The 3-phase current is stepped up from 2,200 volts through three 800 k.w. transformers and delivered to the lines at 44,000 volts. The plant is provided with a 10-ton crane and the usual switchboards and other apparatus, and is protected by two sets of lightning arresters.

Huronian Power Company

The Canadian Copper Company operate all their mines and works by hydro-electric power. This power is obtained from a subsidiary company, the Huronian Power Company, which have developed a water power at High Falls, on the

Spanish river, in the township of Hyman, about four miles from the "Soo" branch of the Canadian Pacific railway, and at a point about 23 miles west of Copper Cliff station. The plant is connected with the railway by a spur line from Turbine station.

The natural head was 67 feet. This has been increased by dams to 85 feet. The effective water-shed is upwards of 2,000 square miles, practically all improved, containing much lake surface. The dams are all of concrete construction on solid rock. From the bulkhead wall four 9-foot penstocks for generators, and one 4-foot for the exciters, are carried down the slope to the power house.

The power house is of brick on a concrete substructure, with steel roof trusses. The building is 110 feet long by 74 feet wide, with an annex 52 feet by 36 feet at one end for workshop and heating boiler. The blower system of heating is used. The generator room is 55 feet wide, leaving 16 feet along one side for transformer rooms and switch tower, which are separated from it by fireproof brick walls and steel doors. Four generating units are installed. Each unit consists of a 2,000-k.v.a. generator, 3-phase, 25-cycle, 2,400-volt, direct-connected to the shaft of a 3,550 h.p. turbine, on which are mounted two 48-inch bronze runners in a single case.

The head is 85 feet and the speed 375 r.p.m.

There are two exciters of 200-k.w. each, either of which can furnish excitation for four generators. Each exciter is driven by a small turbine, direct-connected.

Four sets of transformers, of three each, step up the voltage from 2,450 to 32,000. It is transmitted at the latter figure.

The operators' bench board occupies a central elevated position in front of the switch tower, giving a full view of the generator room and the switching operations in the tower. All switches are distantly controlled, and there is nothing higher than 125 volts on the board.

A small motor-driven air compressor is used to provide air for cleaning purposes and for handling oil.

For fire protection there is a 500-gallon, 2-stage turbine pump, direct-connected to a 40-h.p. d.c. motor, operated from the exciter. The pump suction is connected to the penstocks.

The penstocks, bulkhead gates and screens are housed, and the use of a small amount of current at critical points effectively prevents the building up of ice in the tubes.

The main transmission line is about 30 miles long, from the power house at High Falls to the sub-station at Copper Cliff, for the most part on its own right of way, 100 feet wide, all cleared. It is of double cedar-pole construction, with poles at 8-ft. centres, bolted to a common cross-arm.

There are two independent 3-phase circuits of No. 1 wire, arranged in two equilateral triangles, 4 feet apart and 4 feet to a side. One circuit is transposed and the other straight. The pole stands are placed 120 feet apart.

Branch lines of single-pole, single-circuit construction, run from the main line to Crean Hill mine and Creighton mine, each being about 3½ miles in length. These are both connected to the same main circuit with aerial switches.

Electrolytic lightning arresters are provided outside of the power house and at the sub-stations at Copper Cliff, Creighton and Crean Hill.

A telephone line running along the right of way of the transmission line connects the switchboards in the power house and smelter sub-station. It is carried on a short cross-arm, 6 feet below the main cross-arm, with the wires transposed every fifth pole. A second telephone line, carried for the most part on the poles of the Canadian Pacific railway's telegraph, connects the terminal stations with the Copper Cliff central station, and also with Crean Hill and intervening points.

Preparations are being made for the development of an additional 5,000-h.p. at this plant.

MINING COSTS

Mining costs in the Sudbury district during the year 1915 were higher than may be expected under normal conditions. Supplies in all cases have shown a marked increase due to the war. Moreover, the increased demand for nickel came at a time when the companies had just started extensive development work and were equipping the properties for increased tonnages. This demand had to be met while the developing and equipping of the mines was under way. Consequently current operating costs became a matter of secondary consideration. In general it may be said that the cost of a ton of ore loaded on railway cars at the mines varies between $2.50 and $4.50 per ton, depending on the nature of the ore body, the tonnage mined and the sorting necessary. On a return to normal conditions and the completion of the present schemes of development, these costs, especially at the larger properties, will be materially reduced.

LABOUR

The labour in the district is principally foreign, probably not more than 25 per cent. being Canadian or American. The more skilled workmen, such as foremen, mechanics and carpenters, are Canadian or American. Underground, the drill runners and helpers are principally Finns and Austrians; the trammers are generally Poles, Italians, Austrians and Russians. During the past 10 years the scale of wages has increased about 50 per cent. and the hours of labour have been shortened from 20 per cent. to 33 per cent.

The scale of wages paid for ordinary mine labour is as follows:

	Cents per hour
Drill runners	40½–47
Drill helpers	34½–40½
Trammers	25 –31
Timbermen	40 –47
Scalers	34½–47
Pumpmen	40½
Hoistmen	37½–50
Chute blasters	37½–44
Cage tenders	34½–37½
Surface labourers	25
Rock pickers	25
Machinists	31½–50
Blacksmiths	37½–50
Carpenters	40½–50
Electricians	40½–50

One dollar per month is deducted for medical and hospital attention. Board varies from 60c. to 75c. per day.

In shaft work 3c. an hour extra is paid and a bonus for anything over a specified minimum.

An eight-hour law is in effect for underground labour in Ontario mines. This law requires that men underground in mines shall not work more than eight hours in any consecutive twenty-four hours, such eight hours being reckoned from the time the workman arrives at his working place until he leaves such place. The hours of surface labour at mines are not regulated by statute, and vary from eight to ten, depending on the nature of the work.

WORKMEN'S COMPENSATION ACT

Compensation for accidents in the industry is paid out of a fund administered by a Board appointed under the Workmen's Compensation Act, which came into force January 1, 1915. The mining industry is included in Schedule 1. Industries so classified are not individually liable. The Board levies an assessment and collects an accident fund, out of which the compensation to workmen is paid. Compensation is paid on all accidents arising out of and in course of the employment, except:—

1. Where the disability lasts less than seven days.
2. Where the accident is attributable solely to the serious and wilful misconduct of the workman and does not result in death or serious disablement.

The scale of compensation is as follows:—If the accident results in death and the workman leaves a widow but no children, the widow is entitled to a monthly payment of $20.

If he leaves a widow and children, the payment to the widow is $20 a month and $5 a month for each child under 16 years of age, not exceeding $40 in all.

If he leaves children only, the payment is $10 a month for each child under 16, not exceeding $40 in all.

If the workman was under 21 years of age, and his dependants are his parents, or one of them, such parents or parent will be entitled to $20 a month until the workman would have become 21 years of age, or for such longer time as the Board may determine.

In the case of other dependants, they are entitled to a sum reasonable and proportionate to the pecuniary loss occasioned to them by the workman's death, as determined by the Board.

The necessary expenses of burial, not exceeding $75, are also in all cases to be paid.

All the above is governed, however, by the provision that in no case is the compensation to exceed 55 per cent. of the workman's earnings in the employment, and all provisions for compensation are subject to the proviso that no salary or wages of a workman shall be reckoned at more than $2,000 a year.

In the case of a widow who marries again the periodical payment ceases on her marriage, but she is entitled within a month after her marriage to a lump sum equal to two years' payments.

Where the accident results in total disability of the workman, he is entitled during the continuance of the disability, whether for life or temporarily, to a weekly or monthly payment equal to 55 per cent. of his earnings in the employment. Where the workman is only partially disabled he is entitled to 55 per cent. of the impairment of his earning capacity.

Where less than six workmen are usually employed in mining, including prospecting and development work, except in producing mines where the workmen are in the employ of the owner, lessee or recorded holder thereof, the industry is withdrawn from its class in Schedule 1.

An industrial disease is considered a personal injury by accident, and a workman or his dependants is entitled to the regular scale of compensation. The most common industrial disease in mining is miners' phthisis.

Employers are required to give notice to the Board by registered mail of an accident within three days of its occurrence.

The rate assessed per $100 of payroll on the labour employed in the Sudbury district during the years 1915 and 1916 is as follows. This assessment is collected in two equal instalments, payable in the 1st and 3rd quarters of the year:

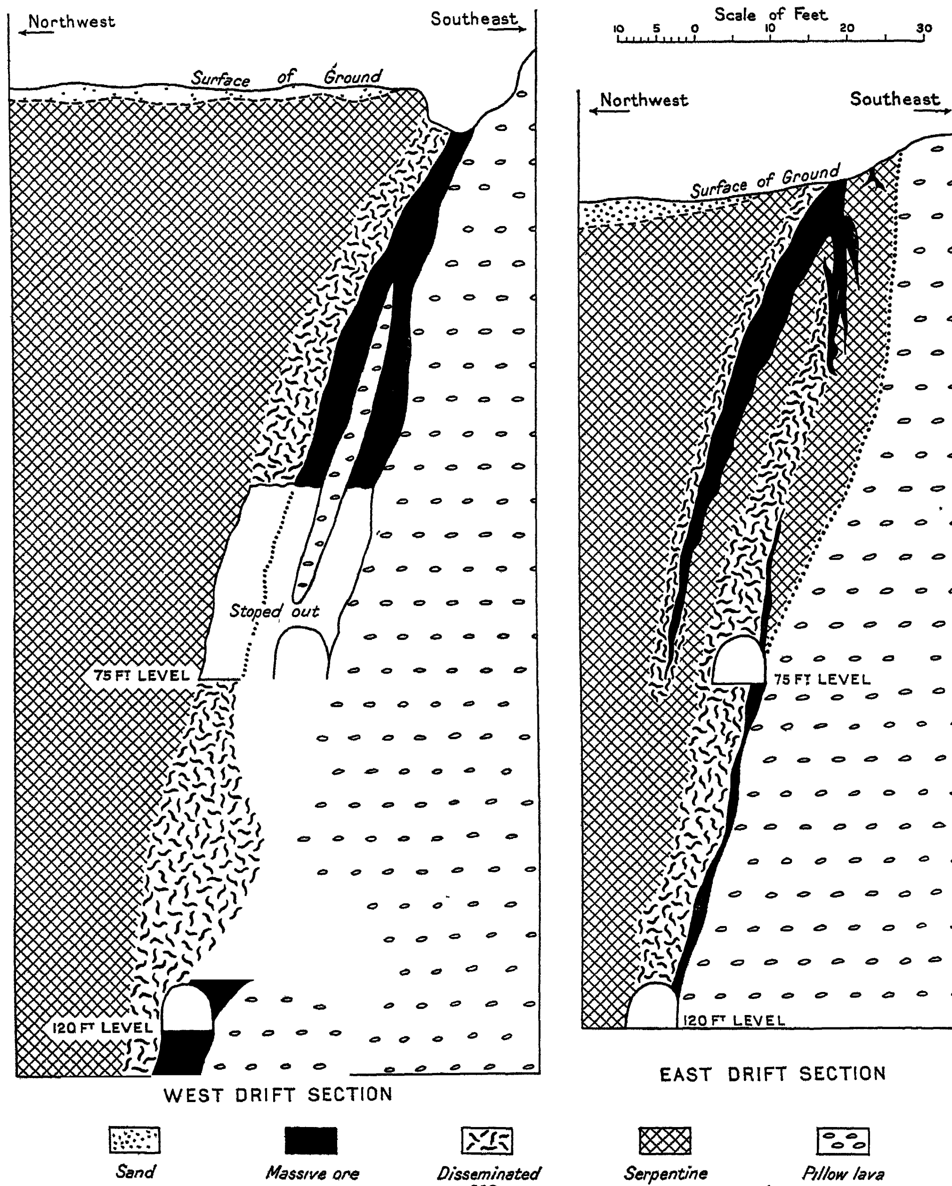
	1915	1916
Mining	$3 00	$2 50
Concentrating, stamping, or other preparations of metals or minerals (without heat)	0 80	0 70
Reduction of ores (with heat), smelting or refining of other metals or minerals	1 50	1 20
Quarries	2 50	2 50
Railroads	6 00	4 00
Power (electrical)	2 50	2 00

CONCENTRATION OF ORES

Under present conditions there is little incentive to employ concentration methods for the nickel-copper ores of Sudbury. Large bodies of ore are worked, the product from which requires little but hand sorting. Some years ago experiments were conducted with magnetic concentrators, the object being to increase the percentage of nickel in the material smelted. No success was achieved. More recently the Mond Company has been experimenting with oil flotation.

Recently H. E. T. Haultain has achieved interesting results in the separation of most of the chalcopyrite from the pyrrhotite and pentlandite.[1]

[1] Can. Mining Journal, Aug. 15, 1916.



Cross-sections through the Alexo ore body, Dundonald and Clergue Townships, Timiskaming District, Ontario. The Figure on the left is a vertical cross-section through the "west" drift; the Figure on the right is a vertical cross-section through the "east" drift. From notes and drawings furnished by Capt. Denmead, of the Alexo mine, and Cyril W. Knight.

TIMISKAMING DISTRICT

The Alexo Nickel Mine*

An area that has attracted recent attention as a source of nickel is situated 150 miles due north of Sudbury. At various places in the Porcupine area and farther north, areas of serpentine have been found, many of which carry pyrrhotite that is frequently nickeliferous. The best of such deposits, yet discovered, is located in lot 12 in the third concession of the township of Clergue and lot 1 in the same concession of the township of Dundonald, and has been given the name Alexo mine from the name of the discoverer, Alex. Kelso.

The rush to the Porcupine gold area, the trail to which passed over this deposit, quite obscured its importance for a while. A drilling option was taken by the Canadian Copper Company, and after an apparently unsatisfactory test, the option was dropped. The owners were not discouraged, however, and decided to open up the property themselves. Major Pullen, one of the owners, undertook the management, and in 1912 he shipped 1,350 tons of ore to the Mond Nickel Company. The mine has continued to ship since that time, and by the end of 1915 had 60,000 tons of developed ore above the 120-ft. level, and with every prospect of further success at greater depth.

During 1916 the company did no further development work, but continued to ship regularly as much ore as possible, in view of the needs of the war office. It is the intention of the owners to resume sinking, and develop deeper levels as soon as power can be spared for this purpose.

The oldest formation in the area is a very compact, hard pillow-lava, of dense texture and a greenish grey colour, when freshly broken; it sometimes has the composition of rhyolite, but more often andesite. There seems little doubt that it is the characteristic Keewatin pillow-lava, so abundant in Northern Ontario. Only twenty miles to the southwest of this, A. G. Burrows has found absolutely similar rocks overlaid by Timiskaming sediments, so their age seems certain. This pillow-lava is so much harder than any other rock of the area, that it always stands up as a prominent feature of the landscape, and thus forms the high hill at the Alexo mine, at the northwestern base of which the ore occurs.

In contact with this pillow-lava is a large mass of peridotite now altered to serpentine. The softer peridotite forms the low, flat, more or less swampy ground about the higher andesite hills. This is an important point for future prospectors of this rock. It is almost invariably the lowest ground to be found in the areas in which it occurs. That these masses are post-Keewatin in age is clear, since they contain fragments of the andesite as inclusions near their contact. This peridotite is so completely altered to serpentine, that it is usually referred to under the latter name.

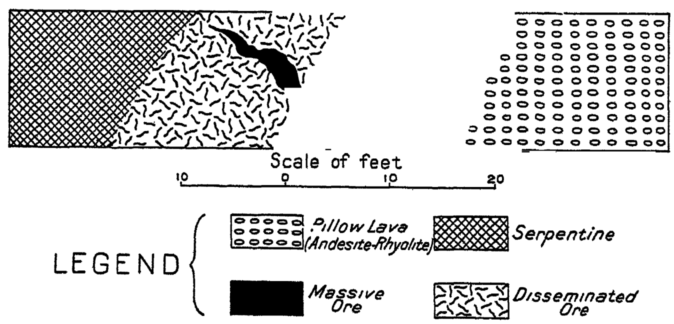
The ore body at the Alexo mine is at the contact of the peridotite with the earlier pillow-lava The ore is one of two distinct types. The first is disseminated throughout the peridotite. The second is pure or massive sulphide which occupies spaces, cracks, or other openings along the actual contact, or finer fractures in either wall. The contact of the two rocks strikes northeast and southwest, and has a dip

*M. B. Baker, Professor of Geology at Queen's University, Kingston, Ontario, has written for the Commissioners the following account of the Alexo mine.

of 65 to 80 degrees to the northwest. The deposit has a proven length of 700 feet, and has been opened up to a depth of 120 feet, and diamond drilling has shown ore at a depth of 240 feet. The width of the ore body, counting both the massive and disseminated ore, is variable. On the 120-ft. level, for example, it is 40 feet wide, while at places on the 75-ft. level it is not more than 3 feet. It will average, on all the work done so far, probably 10 feet.

The massive ore consists almost entirely of pyrrhotite, with small amounts of pyrite, chalcopyrite, and pentlandite in mere filaments through the mass. The pentlandite can only rarely be seen with the naked eye, but polished and etched pieces of the ore show it in very fine veinlets threading their way through the massive sulphides. Chalcopyrite is not at all abundant, and occupies small fractures, as if introduced after the pyrrhotite. The smelter returns show less than one per cent. of copper. This massive ore rests directly on the footwall of andesite.

The hanging wall of the massive ore is disseminated ore, wherever the normal structure has not been disturbed by faulting. The contact between massive ore and disseminated is just as clean and sharp as is that between massive ore and the andesite. Small stringers of massive ore also penetrate the disseminated, and fragments of the latter are sometimes enclosed in the massive; all of which goes



Cross-section at the Alexo nickel mine, on the 120-foot level, Dundonald and Clergue Townships, Timiskaming District, Ontario. The massive ore cuts through the disseminated ore, and was deposited at a later period in the history of the ore body than the disseminated ore. This age relation between the massive and disseminated ore is also shown in the two preceding cross-sections.

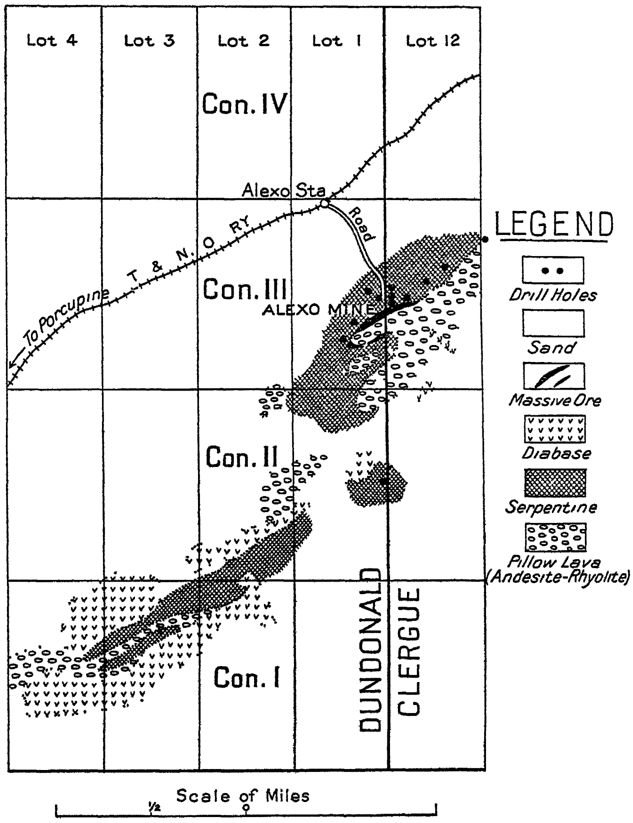
to show that there were two distinct periods of ore deposition, and that the massive ore was the later of the two.

Since this property was described by A. P. Coleman,[1] and W. L. Uglow[2] much work has been done underground, permitting a closer examination of the ore body than was possible at that time. They claimed that the massive ore, the disseminated ore, and the serpentine rock blend into one another. This is certainly not the case, for a sharp contact exists, which is actually slickensided, between the massive ore and the disseminated. The disseminated ore is always scattered throughout the rock, forming part of its texture and structure, and grades off into barren serpentine; it is only mined as far as it is economical to

[1] Dept. of Mines, Canada, 1913, The Nickel Industry.
[2] Ont. Bur. of Mines, Vol 20. Part II.

do so, there being no wall in the ordinary conception of that term. Beyond this transitional phase of the ore, the serpentine is absolutely barren of sulphides, even when viewed microscopically.

Coleman and Uglow differ in their opinion as to the origin of the ore body. Coleman compares it to the deposits of nickel-copper ore at Sudbury, and claims that the massive and disseminated ore are due to magmatic segregation, whereby the sulphides settled out as would matte from slag, and therefore occupy the base or margin of the peridotite body, and gradually passes up into it.



Geological map of the Alexo mine and vicinity, Dundonald and Clergue Townships, Timiskaming District, Ontario.

Uglow, on the other hand, claims that the Alexo ore body is the result of metasomatic replacement of the serpentine rock by sulphide solutions, which worked inward from the contact, replacing partly to completely the serpentine rock.

A study of the ore body, microscopic examinations of polished ore specimens and of thin sections by the writer, cause him to differ from both of these theories. While it is impossible to enter into a full discussion of this subject here, the following points will summarize the results of the writer's observations.

1. It has been already shown that the massive ore is distinctly later in age than the disseminated, and is therefore not a magmatic segregation of the main intrusive mass.

2. The disseminated ore preserves perfectly the rock texture and structure of the mass.

3. Even the richest of the disseminated ore shows the original olivine crystals intergrown with and surrounded by pyrrhotite but in no case replaced by the latter. The intergrowth is as sharp and clear cut as is that between quartz and feldspar in graphic granite.

4. Even in the leanest ore there is no sign of attack of any replaceable mineral. The few grains of sulphides visible are in sharp, angular, clean cut contact with the idiomorphic olivine crystals.

5. In no single case was absorption of the olivine crystals visible, although it is clear that the olivine crystallized before the sulphides.

6. Apparently barren peridotite, away from the ore body, shows by analysis 0.59 per cent. of nickel oxide.

It seems clear, therefore, that the disseminated ore was formed as an original constituent of the peridotite, that it settled to the base of the magma by its greater specific gravity, but remained liquid through its lower fusion point. Finally it solidified about and around the olivine crystals which had already formed, and had settled down into the liquid sulphides. This accounts for the disseminated ore.

After the whole mass had solidified, it continued to cool, and therefore to shrink, and a channel was opened along the contact to deeper portions of the mass, where solidification had not yet taken place. This allowed further sulphides to well up and fill all openings and fissures, thereby forming the massive ore as now found. This being the case it is evident that prospectors searching these serpentines will find deposits of disseminated ore, which will carry no massive ore, and vice versa. It is doubtful whether a deposit of disseminated ore alone, could be worked at a profit. The massive ore of the Alexo mine carries 6 to 8 per cent. of nickel, while the disseminated carries 3 per cent. The two varieties are mined and shipped together, about 40 per cent. of the former with 60 per cent. of the latter. This makes a shipping product of about 4½ per cent. nickel ore.

An interesting feature of this ore is its magnesium content. This is important for while the Canadian Copper Company requires to add dolomitic limestone to its smelter charge, the Mond Nickel Company is able to use Alexo mine ore. The barren limestone is bound to slag off some nickel in the process of smelting, whereas the serpentinous Alexo ore, with its even distribution of ingredients, contributes as much nickel contents as would any other ore, and adds the fluxing requirements as well.

NICKEL ORES ELSEWHERE IN CANADA

Metallic nickel and nickel oxides are produced in small quantities by refiners of the silver-cobalt-nickel-arsenic ores of the Cobalt, Ont., deposits. Numerous descriptions of these deposits have been published, and it is not necessary to repeat them here.[1] It may be added, however, that these ores are not worked primarily as a source of nickel, but chiefly for their silver, the other metals, cobalt, arsenic and nickel, being more of the nature of by-products.

If the mines of Sudbury, Alexo and Cobalt are excepted, it can be said that Canada possesses elsewhere no known deposit of nickel of economic importance. Barlow has published a good description of the occurrences of nickel ores or minerals in the Dominion, which have not been proved to be of commercial value.[2]

Among these the only deposits worthy of note, as being of possible commercial importance, are those near St. Stephen, New Brunswick. These deposits resemble in many respects those of Sudbury, but are of small size, in so far as is known, and carry lower percentages of nickel and copper.[3]

NICKEL DEPOSITS OF OTHER COUNTRIES

The nickel deposits of Canada having been described on preceding pages, a brief survey of the nickel resources and industry in other countries will now be undertaken. The deposits first to be discussed will be those of New Caledonia and Norway, which are the largest producers of the metal after Ontario. Brief descriptions will then be given of deposits in other parts of the world, although most of them are of comparatively little economic importance. They are small, and were the price of refined nickel to be materially reduced they would be of practically no value. Indeed, there is reason to believe that in a real competition for the markets of the world, which would mean a lowering of the price of refined nickel, Sudbury would easily vanquish all competitors.

It is an interesting fact that the British Empire and French possessions now control the market. Nickel deposits of the Empire, in addition to those of Canada, are represented by small ore bodies in Tasmania, from which a few thousand tons of ore, similar mineralogically to that of Sudbury, have been shipped. Silicate ores, similar to those of New Caledonia, occur in Egypt, and there are the small deposits of pyrrhotite-chalcopyrite ores of South Africa. In addition to the New Caledonia deposits, France possesses ores of similar character in Madagascar. Norwegian ores are similar to those of Sudbury, but occur in small deposits, and are of low grade. Greece possesses silicate ores, resembling those of New Caledonia, and has made shipments during recent years to smelters in Norway and elsewhere. Germany and Austria possess a number of small deposits of various kinds of ores that can be worked when nickel is high in price. The nickel resources of the United States, briefly described on a following page, are of little importance. Brief descriptions of the nickeliferous iron ores of Cuba and of one or two other countries are also given on following pages.

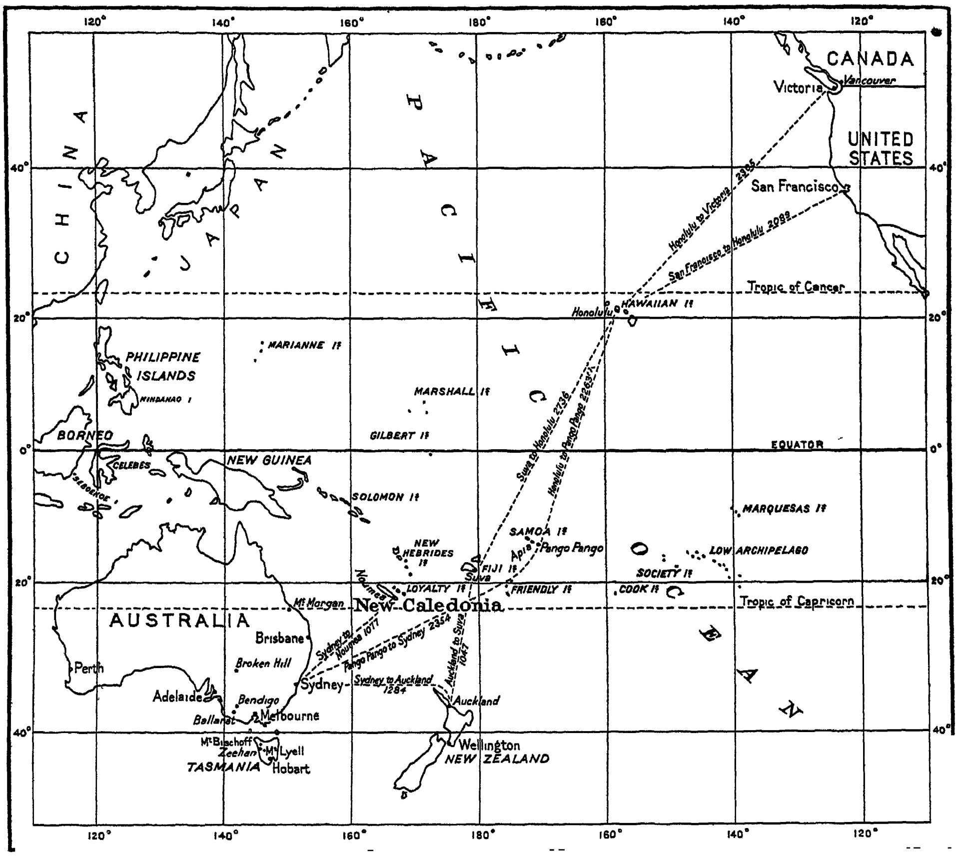
[1] Ont. Bureau Mines, Vol. 19, Part II, 1913

[2] A. E. Barlow, Nickel and Copper Deposits of the Sudbury Mining District, Geol. Sur. Canada, No. 961, pp. 145-164, 1907.

[3] C. W. Dickson, Can. Mining Inst., Vol IX, pp. 234-260. H P. H. Brumell, Geol. Sur. Can., Vol. IV, 1890-91, Part SS, pp. 112-114. R. W. Ells, Summ. Rept Geol Sur. Can., 1903, pp. 156-159.

NEW CALEDONIA

In several official reports descriptions are given of the island and of its mineral deposits. The last and most detailed report on mining operations, published in 1904, is by E. Glasser, and is addressed to the French Minister of the Colonies. The title is "Les Richesses Minérales de la Nouvelle-Calédonie," and it contains references to earlier literature.[1] Since Glasser's report was issued little has been published that gives a general description of the mineral resources and the mining industry of the colony. Reference should be made, however, to a few



Map of Part of South Pacific Ocean.

papers. Two of these are by G. M. Colvocoresses, one entitled, "New Caledonia and its Mines," and the other "Nickel Mining in New Caledonia," Engineering and Mining Journal, New York, Sept. 21st and 28th, 1907. These papers, while consisting of only about eight pages, give a clear and interesting account of mining and other conditions. Another instructive paper dealing with the physical features together with the fauna and flora, and referring briefly to the mineral wealth, was read before the Royal Geographical Society in 1916, by R. H.

[1]The chief reports preceding Glasser's are by the following authors: Garnier, Annales des mines, 1867; Heurteau, ibid, 1876; Pelatan, Journal le Genie civil, 1892; Levat, Ass. Fran. Ad. Science, 1887.

Compton, who spent the whole of the year 1914 in the island. There are other papers in English that should be mentioned. Two of these are published in the Transactions of the Institution of Mining and Metallurgy, the earlier one, "Nickel Mining in New Caledonia," by J. Garland, in volume II, and the later, "The Mineral Resources of New Caledonia," by F. Danvers Power, in volume VIII. A. G. Charleton published two useful papers in the Journal of the Society of Arts, volumes 42 and 43.

Historical Notes

A few notes may not be out of place on the discovery of New Caledonia and its subsequent history.

The following brief description of the discovery of the island, on the 4th of September, 1774, owing to the keen and accurate observations and the useful information it contains, make it worthy of consideration at even this distant date. The quotations are from Captain Cook's "Voyages Round the World," and the language is that of the great navigator himself.

> Having now finished the survey of the whole archipelago [New Hebrides], the season of the year made it necessary for me to return to the south while I yet had some time left to explore any land I might meet with between this and New Zealand, where I intended to touch, that I might refresh my people and recruit our stock of wood and water for another southern course.
>
> No more land was seen till eight o'clock on the 4th, when land was discovered bearing S.S.W., for which we steered. We had hardly got to an anchor before we were surrounded by a great number of the natives in sixteen or eighteen canoes, the most of whom were without any sort of weapons. At first they were shy of coming near the ship, but in a short time we prevailed on the people in one boat to get close enough to receive some presents. These we lowered down to them by a rope, to which in return they tied two fish that stunk intolerably. These mutual exchanges bringing on a kind of confidence, two ventured on board the ship, and presently after she was filled with them, and we had the company of several at dinner in the cabin. Our pea-soup, salt beef, and pork they had no curiosity to taste, but they ate of some yams which we happened to have yet left. Like all the natives we had lately seen, the men were almost naked. They were curious in examining every part of the ship, which they viewed with uncommon attention. They had not the least knowledge of goats, hogs, dogs, or cats, and had not even a name for one of them.
>
> We landed on a sandy beach before a vast number of people. Many of them had not a stick in their hands, consequently we were received with great courtesy, and with the surprise natural for people to express at seeing men and things so new to them as we must be. Here we found the chief, whose name we now learned was Teabooma, and we had not been on shore above ten minutes before he called silence. Being instantly obeyed by every individual present, he made a short speech. It was pleasing to see with what attention he was heard.

Captain Cook's reasons for not further exploring New Caledonia are given by him as follows, and they seem sufficient answer to those writers who have criticized him, in this connection, at various times.

> We also found on the isle a sort of scurvy-grass and a plant called by us lamb's quarters, which when boiled ate like spinach. I had now to consider what was next to be done. We had from the top-mast head taken a view of the sea around us, and observed the whole to the west to be strewed with small islets, sandbanks, and breakers to the utmost extent of our horizon. But when I considered the great risk attending a more accurate survey, and the time it would require to accomplish it, on account of the many dangers we should have to encounter, I determined not to hazard the ship down to leeward, where we might be so hemmed in as to find it difficult to return, and by that means lose the proper season for getting to the south.
>
> Next morning at daybreak we got under sail, with a light breeze at E. by N.
>
> On the morning of the 3rd [Oct.] the wind veered to S.W., and blew a strong gale by squalls, attended by rain. I now gave over all thought of returning to the land we had left. Indeed, when I considered the vast ocean we had to explore to the south, the state and condition of the ship, already in want of some necessary stores, that summer was approaching fast, and

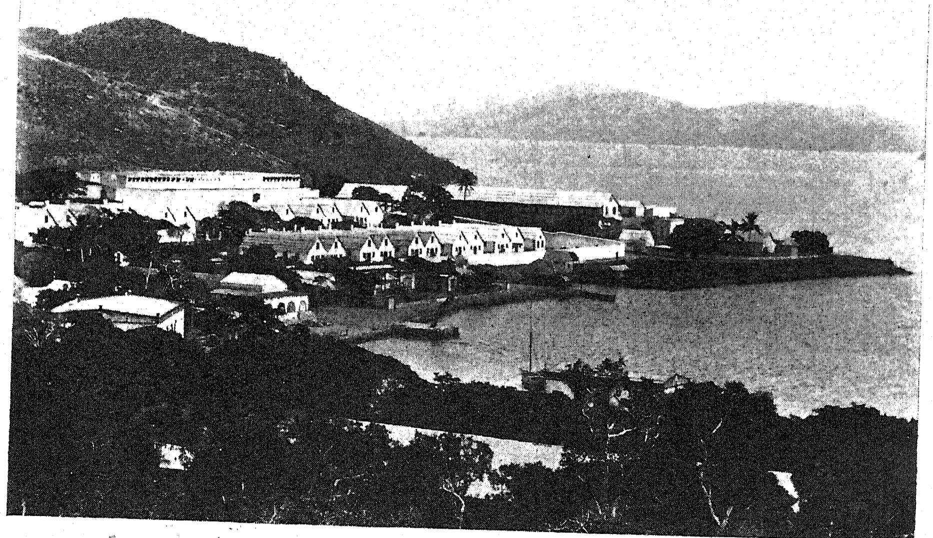
that any considerable accident might detain us in this sea another year, I did not think it advisable to attempt to regain the land.

Thus I was obliged, as it were by necessity, for the first time to leave a coast I had discovered before it was fully explored. I called it New Caledonia, and, if we except New Zealand, it is perhaps the largest island in the South Pacific Ocean.

The language at Atooi is almost word for word the same as Otaheite. How shall we account for this nation's having spread itself in so many detached islands, so widely disjointed from each other, in every quarter of the Pacific Ocean? We find it from New Zealand in the south as far as the Sandwich Islands [Hawaii] to the north; and in another direction from Easter Island to the Hebrides.

French Possession

For over three-quarters of a century, after Captain Cook's discovery, no civilized nation laid claim to the island. However, missionaries to the natives established themselves there, and in 1854 the French took possession. It is said that a French and a British frigate started at the same time from Sydney,

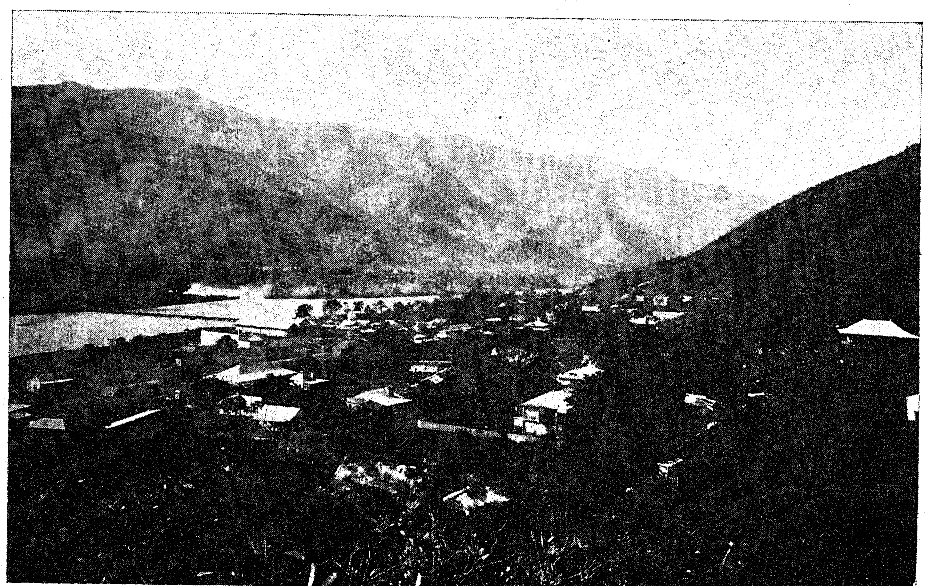


The Great Prison of Isle Nou, New Caledonia.

Australia, for the island in order to take possession of it, but that the Frenchman had the good luck to be the first to find a passage through the barrier reef and thus secure for his nation this island that is, as Cook conjectured ". . . . if we except New Zealand, ... the largest island in the South Pacific Ocean." Thus was gained for France and lost to Britain the largest mineral territory, excepting Australia and New Zealand, in that quarter of the world.

In 1864, the French established a penal settlement, and the island has become widely known as an abode of criminals, as well as a producer of nickel, cobalt and chromium. For some time after mining began, the industry was assisted by cheap convict labour, there being at one time more than 12,000 convicts. For nearly twenty years, however, no convicts have been sent to the island, and other labour supply has been obtained. It may be added that several hundred men still linger as prisoners in the colony. Since transportation of convicts ceased its prosperity has declined.

It is a striking fact that two countries, so widely separated as are Ontario and New Caledonia, not only by distance, but in almost every other way, should alone be rivals not merely in the production of nickel, but in that of cobalt as well. In preceding pages it has been shown that, before the advent of Sudbury, nickel from New Caledonia controlled the world's market. Likewise, before the discovery of the cobalt-silver deposits at Cobalt, New Caledonia had a monopoly of the cobalt market; the industry on the island colony has now been killed by that of Ontario. It may be added that New Caledonia is an important producer of a third mineral product, chromium ore. One of its mines, the Tiebaghi, is among the world's largest producers of this ore.



New Caledonia Topography.

Physical and Other Characteristics of New Caledonia

The island of New Caledonia is situated between latitude 20°5′ and 22°16′ S. and between longitude 164° and 167°50′ E. It has a length of about 250 miles and an average breadth of less than 30 miles, the maximum being about 40; the longer axis lies in the direction N.W.—S.E. The port of Nouméa, the capital of the island, is distant about 1,077 nautical miles northeast of Sydney, Australia, and a passenger service is maintained between the two places. The coast of Queensland lies about 700 miles from the island.

An almost unbroken barrier reef, distant one to seven miles, skirts the west shore of the island, enclosing a channel which is navigable along most of the coast. On the east coast, which is rugged, the reef is more broken.

The island is exceptionally mountainous, the highest points being Mount Humboldt, 5,360 feet, in the south, and Mount Panié, 5,345 feet, in the north. The assemblage of mountains is frequently spoken of as the "chaine centrale," but this term, as has been pointed out by several writers, does not give a correct

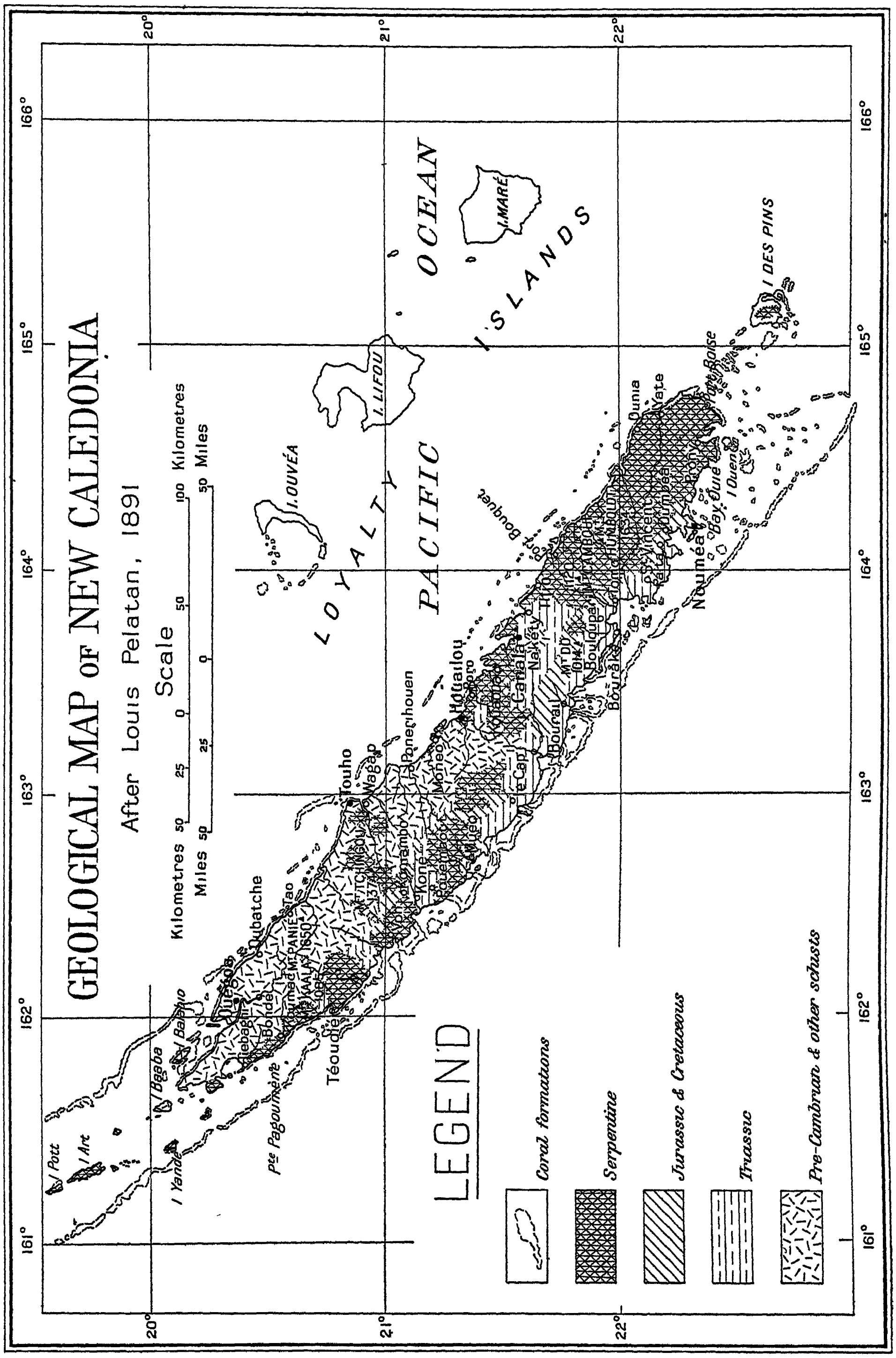
description. The island consists largely of confused masses and ranges of mountains, which, over much of the colony, lie near the coast, especially on the east, and cannot be said to form a chain running lengthwise through the central part. Many of the plains are deltas of rivers. The coastline is broken by numerous small bays into which flow streams rarely navigable even for short distances. The rugged bare mountains, with a fringe of small areas of level land here and there along the coast, frequently supporting cocoa palms or other tropical vegetation, present a scene of great contrast that is impressive and beautiful.

The accompanying geological map, after Pelatan, shows the distribution of rocks of various kinds in the island. It will be seen that supposed Archean or pre-Cambrian rocks occur in small volume, more especially in the north of the island. Sedimentary rocks are classed as of Triassic, Jurassic and Cretaceous age, the latter containing unworked beds of coal. The serpentine series, which occupies about one-third of the surface of the island, is thought to be of post-Cretaceous

Natives.

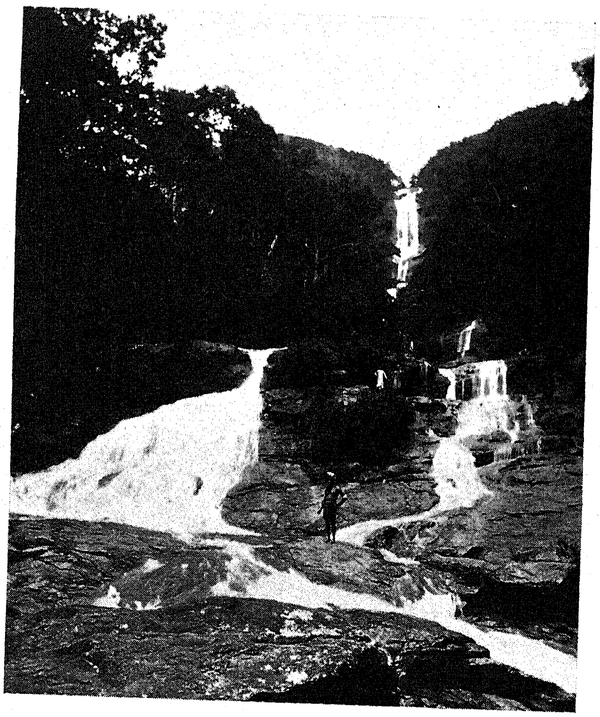
age. From the mining point of view, this series is the most important in the island, as associated with it are the deposits of nickel, cobalt and chromium. Over much of its surface the serpentine series has deposits of nodular iron ore, many of the nodules being little larger than a pea, together with other products of weathering, including deposits which are workable as sources of nickel and cobalt. The serpentine forms mountains with steep sides and usually with narrow summits, thus differing from the areas of similar rock in Cuba, which form more plateau-like structures on which lie productive iron ore deposits. Recent limestones are represented by coral reefs along the coast of New Caledonia.

The climate of the island is not unlike that of Cuba, which lies about the


GEOLOGICAL MAP OF NEW CALEDONIA
After Louis Pelatan, 1891
Scale
Kilometres 50 25 0 50 100 Kilometres
Miles 50 25 0 50 Miles
LEGEND
Coral formations
Serpentine
Jurassic & Cretaceous
Triassic
Pre-Cambrian & other schists
LOYALTY ISLANDS
PACIFIC OCEAN
I. OUVÉA
I. LIFOU
I. MARÉ
I DES PINS
Nouméa
Touho
Téoudié
Ounia
Yate
Port Bouquet
Canala
Bourail
Houailou
Kone
Poneríhouen
I Art
I Pott
I Yande
Pte Pagoumène
161°
162°
163°
164°
165°
166°
20°
21°
22°

highest temperature on record is 103°F. and the lowest 38°, but the maximum does not usually exceed 97°. The mean minimum is 63° and the mean maximum 83°. December, January and February are the hottest months and June, July and August the coolest. Trade winds modify the summer temperatures.

According to statistics compiled by Compton, the average rainfall from 1908 to 1912 was 1,845 mm. (72.6 inches) per annum distributed over 142 rainy days. Heavy rains may occur throughout the year, but, generally speaking, it is possible to distinguish a rainy season in January, February and March, and a dry season in September, October and November. The total rainfall varies greatly in different years. The mean in 1910 was 2,439 mm. (96 inches) and in 1911 it was 1,264 mm. (49.7 inches).



A New Caledonia Water Fall.

The island is visited by cyclones, which occur almost exclusively in the months of January to March, and are often destructive to buildings and to cocoanut and other trees. For this reason many buildings of light structure are supported by wire cables.

Although there is merchantable timber, little is cut, owing chiefly to the mountainous character of the country.

Cattle do well on the island, but in seasons of drought there are sometimes excessive losses. More attention to water supply, by the building of dams, would largely overcome these losses. Sheep are not a success; horses appear to thrive.

New Caledonia coffee brings a high price as compared with that from many other countries, but during recent years the plants have been attacked by a fungus which has been very destructive.

The agricultural exports are preserved meats and other animal products, coffee, copra and cotton, although maize, rice, bananas, oranges and various vegetables, are grown. On the whole agriculture has been neglected. In addition to ores, other exports are pearl shells, essences, sandalwood, a little rubber, and a few other materials.

The flora of New Caledonia, according to Compton, who made a special study of it, is large and varied and presents many exceptional features. The most striking feature of the fauna is the almost complete absence of mammals. The only representatives of this group native to the island are the bats and flying-foxes together with a rat and a pig, the latter two apparently dating from pre-historic times. An East Indian stag or deer has been introduced, and is now locally so abundant as to be almost a nuisance.

There are no marsupials or amphibians, though the French have introduced a species of frog. Land snakes are absent, but lizards are represented by several species of skink and gecko, including one of exceptional size. Birds are not numerous in species, but contain representatives of most of the families. The kagou is perhaps the most remarkable; it has large, well-developed wings, but is entirely flightless.

Of the insects it need only be said that mosquitoes are a great pest in certain localities, but they are fortunately not of the disease-breeding varieties. There are spiders and scorpions, and a variety of molluscs, including the "oyster on trees." Troca-shell and biche-de-mer are exported. There is an abundance of good sea fish; sharks are numerous.

To again quote Compton: "The native population of New Caledonia is a branch of the Melanesian stock, and there is some reason to think it may be among the most primitive of that group of races. As to the relations of the New Caledonian race with those of the surrounding land masses, it appears probable that they are more closely connected with the natives of Australia than with those of the New Hebrides or the Solomon Islands." Cannibalism was formerly frequent.

The cosmopolitan character of the population is well described by Colvocoresses in the following sketch of Nouméa, the capital and chief town of the island:—

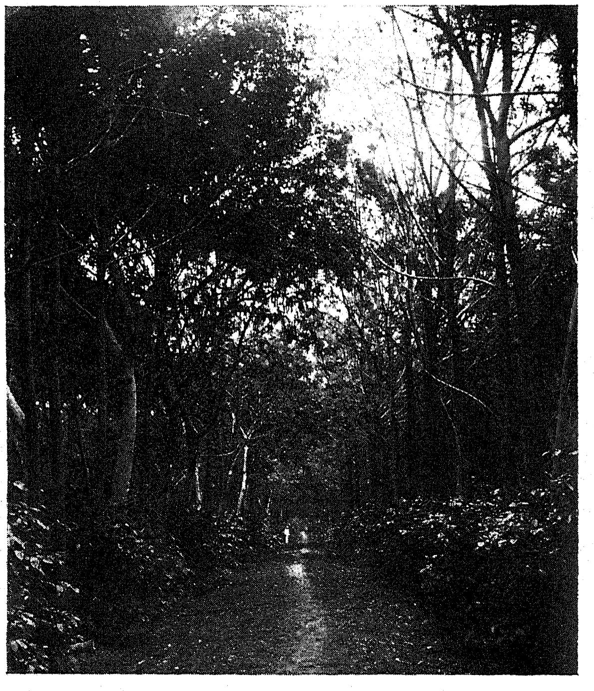
But for other reasons Nouméa is one of the most curious and interesting of towns to be found anywhere. It is all white and green, with the bluest of blue skies overhead, and the tropical sun is reflected from the sheet-iron roofs and seems actually to shine up from the limestone pavements, so that the continual glare is most trying on the eyes. Yet a cool breeze almost always blows, and water from the reservoir on the hill trickles pleasantly down on either side of the streets, and the cocoa-palms and flamboyants (a species of locust tree with brilliant red flowers) lend shade and colour. Its population is about 8,000, and on the streets one sees the most motley crowd of people, especially on Sundays, when all are out in the square to listen to the music, patronize the Italian bazaars and cake stalls or risk their money on the "petits-chevaux." French officers and business men, English and Australians of all classes, Austrian and French labourers, traders, beach-combers, and ex-convicts, make up the European element. Next the Arab convicts and exiles from Algeria. Then come all shades of colour—Japanese, Chinese, Tonquinese, Annamites, Javanese, Singalese, Malabars, Hindoos, Polynesians from the Loyalty islands and the Malaysian race of islanders from the New Hebrides, Solomons and New Caledonia itself. Each nationality clings largely to its national costumes and talks its own language with "pidgin-French" or "Bech-de-mer" as a means of communication between all. The square on Sunday is truly a babel.[1]

[1]Eng. & Min. Jr., Sept. 21, 1907, pp. 532-3.

According to the census of March, 1911, the population of the island was 50,608, made up as follows: Whites, 19,319; Asiatic immigrants, 3,214; natives, 28,075. The white population at that time consisted of 13,138 free, 396 troops, 114 mercantile marine crews, and 5,671 convicts.

Fevers that are prevalent in certain tropical or semi-tropical islands are absent and the climate is healthful, but the natives suffer from a number of diseases such as consumption, elephantiasis and leprosy, the latter of which is making some headway even among the white population.

Means of communication throughout the colony are poor. Little in the way of road building has been attempted. Trails lead across the island here and there, but, owing to the mountainous character of the country, they are unsuited for



Coffee Plants Growing in Shade of Trees.

transport. The only waggon road of importance is that connecting Nouméa with Bourail, about 100 miles in length. A narrow-gauge railway connects Nouméa with Paita, and there are two or three short lines of railway, used for carrying ore, connecting the interior mines with the coast. The chief means of transport are the small steamers which ply about the coasts.

Mining Progress [1]

Although Garnier discovered nickel in New Caledonia in 1865, it was not known to occur in economic quantities till the end of 1874, when Heurteau made his optimistic report. Discoveries multiplied rapidly, and over 300 tons were exported in

[1] Tons referred to in this section are metric tons of 2,204 lbs. each. Kilogram=2.204 lbs. Franc=19.3 cts.

1875. In the years 1876-7 a total of nearly 8,000 tons of ore containing 8 or 10 per cent. of nickel was shipped from the island. Mining was completely arrested in 1878-9 owing to the Kanaka insurrection.

Finding the freight, about 100 francs a ton, on ore to Europe excessive, furnaces were erected near Nouméa and ore was smelted between 1879 and 1885, about 4,000 tons of matte being exported. It is interesting to note that half of the ore smelted during that period came from the mines on the Plateau of Thio which are still in operation. In this period only the rich ores were sought for in these mines, at first especially the green-coloured material and later the chocolate.

The value of metallic nickel fell lower and lower as production increased. At the end of 1881 it had fallen to 8 francs a kilogram and to 6 at the end of 1884. On the other hand the production, which was 400 tons annually for the entire world at the time of the discovery of the New Caledonia deposits, was more than doubled in the course of less than a dozen years, and quickly passed the needs of consumers.

At the end of 1884 the stocks of ore accumulated in New Caledonia, as well as those of metal in Europe, caused the demand for nickel to be lessened to such a point as to arrest the working of the mines; the furnaces at Nouméa ceased operations at the end of 1885.

Exports, already lessened in 1885, fell to 920 tons of ore in 1886, those of matte having already ceased; prices had also fallen to such an extent that ore carrying 10 per cent. of nickel, valued ten years before at 1,000 francs a ton, now brought only 200

Mining development kept pace with the demand for nickel and conditions changed as time went on. The percentage of metal in the ores exported decreased from 10 or 12 to 7 or 8, and the price fell to 125 francs a ton, or 1.50 to 1.60 francs a kilogram of metal contained, as compared with 2 francs in 1885 and 10 francs in 1876. A new era of production opened under these conditions and exports of ore increased rapidly. Consumption increased owing to the extension of the older industries that used nickel as a raw material and especially to the introduction of nickel steel. Smelting was again undertaken on the island and exports of matte were made in the years 1889-90-91.

This period of prosperity of some years' duration, unfortunately for New Caledonia, was abruptly checked by competition from the Sudbury deposits, nickel from which began to be produced in 1887. Initial difficulties in treatment of the ores and trade prejudices, as regards the character of the metal, having been overcome, Sudbury in a few years became a serious competitor. New Caledonia exported ore and matte, representing together a total of about 55,000 tons of ore in the year 1891, and did not again reach so large an output for a period of five years, the shipments for these periods being: 1892, 35,951 tons; 1893, 45,613; 1894, 40,089; 1895, 38,976; 1896, 37,467, and 1897, 57,639. This illustrates the effects of competition with Sudbury.

During the period of competition the price of nickel was lowered materially, and, as the costs of freight on ore to Europe and treatment were susceptible of little

change, the tendency was to lower the price paid for ore in New Caledonia; from 125 francs in 1888 it had already fallen to 80 at the beginning of the period of competition, and it fell to 35 francs for 7 per cent. ore in 1897, which represented not more than 0.50 franc a kilogram of metal. According to Glasser the period of competition was ended by an understanding between the refiners of New Caledonia ores and those of Sudbury by which the nickel output from each country was controlled.[1] This permitted the resumption of exportation of ore from New Caledonia under more normal conditions and shipments increased, being 74,614 tons in 1898 and 103,908 in 1899. At the same time the price of ore in New Caledonia, which had fallen to 35 francs a ton, rose to about 50. Over-production, as has happened at various times, caused a lowering of the quantities exported in 1902 and 1903 as compared with those in 1901.

Referring to the output of the mines in the period of increased production preceding the year 1903, Glasser notes that the increase was not accompanied, as in former periods of expansion, by a reduction in the nickel content of the ores. Freight costs on ore to Europe did not permit the shipping of ores of much lower grade. The increased production was due not only to the older mining centres, those of Thio, Canala, Kouaoua and Koné, and also to a less extent to those in the district tributary to Nouméa, but by the development of new centres; these centres were multiplied along the west coast of the island, where the green silicates and chocolate ore are relatively rare, but where masses of nickeliferous breccias and altered nickeliferous serpentine, which are abundant and had been recognized for some years as being more profitably mined than the ores formerly sought.

The following table gives the quantities of ore and matte exported during each of the years, 1900-1915. The shipments of matte show that during the last six or seven years smelting has been revived That it has been a success is evident from the fact that smelting plants are being enlarged and the production of matte will soon be increased. Hydro-electric power is being developed, which may be used to some extent in smelting operations.

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[1] On another page Glasser has the following to say concerning the effects of Sudbury competition, but of course he wrote in 1904, and New Caledonia no longer holds first place as a producer:—

"Canada, on the contrary, has shown herself to be a formidable competitor of New Caledonia, and, if the figures we have given above show that, in spite of this competition, our colony remains to-day the premier producing country of nickel in the entire world, it has not been without a strenuous struggle, in the course of which the price of nickel fell to 2 fr. 40 a kilogram, [or 21 cents per lb.], causing the closing of nearly all the mines of the colony, and obliging La Société le Nickel, the principal exploiter of nickel in New Caledonia, to suspend all distribution of dividends during a period of five years." Page 233, Glasser.

"The price of metallic nickel has been lowered considerably during the last twenty-five years, since at the time of the discovery of the ore in New Caledonia it was 18 francs a kilogram, afterwards falling rapidly to 10 francs, then successively to 8.6 and 5 francs (1892), to 4 francs (1894), and 3 francs (1895), and then even to 2 francs 40 (end of 1895), owing to Canadian competition; it oscillates mainly between 3 francs 50 and 4 francs a kilogram." Page 207.

N*95.—Price 2 fr. .40 per kilogram=21 cents per lb.
" 3 fr. .50 " " =30.6 " "
" 4 fr. " " =35 " "

EXPORTATION OF NICKEL FROM NEW CALEDONIA, 1900 TO 1915, METRIC TONS.

Year.	Ore.	Matte.
1900	100,319	......
1901	133,676	......
1902	129,653	......
1903	77,360	......
1904	98,655	......
1905	125,289	......
1906	118,890	......
1907	119,000	......
1908	108,000	......
1909	86,000	......
1910	99,000	768
1911	142,000	2,993
1912	74,314	5,908
1913	93,190	5,893
1914	94,154	5,277
1915	48,576	5,529
Total	1,648,076	26,368

STATEMENT GIVING DETAILS OF NICKEL ORES AND NICKEL MATTES EXPORTED FROM NEW CALEDONIA DURING THE YEARS 1913-14-15.

Shippers.		Tons of 1,000 kilos.
1913.		
Nickel Ore.		
Société le Nickel	51,306,642	
G. de Béchade	9,111.000	
		60,417.642
Société Hauts-Fourneaux de Nouméa (Ballande)		27.097 225
Société des Mines du Mont Do		5,675 394
Total		93,190.261
Nickel Matte.		
Société le Nickel		2,314.460
Société de Tao		123.995
Société Hauts-Fourneaux de Nouméa (Ballande)		3,454.743
Total		5,893 198
1914.		
Nickel Ore.		
Société le Nickel	57,283,615	
G. de Béchade (Le Nickel Corporation)[1]	15,626.960	
		72,910 575
Société Hauts-Fourneaux de Nouméa (Ballande)		18,346.596
Société des Mines du Mont Do[2]		2,800.000
J. Birch & Co.		97 265
Total		94,154.436
Nickel Matte.		
Société le Nickel		2,493.650
Société Hauts-Fourneaux de Nouméa (Ballande)		2,753 712
Société de Tao		29.779
Total		5,277.141
1915.[3]		
Nickel Ore.		
Société le Nickel		43,584.000
G. de Béchade		4 992.000
Total		48,576.000
Nickel Matte.		
Société le Nickel		1,400.000
Société Hauts-Fourneaux de Nouméa (Ballande)		4,129.167
Total		5,529 167

[1] Le Nickel Corporation is a subsidiary of the International Nickel Company.
[2] This company is said to have been a subsidiary of Krupp's.
[3] According to Le Bulletin du Commerce, Noumea, February 10, 1917, p. 13, the production of nickel ore in New Caledonia for 1916 was 30,679.245 metric tons, and of nickel matte, 4,935.167 metric tons.

Details at hand concerning the industry are more complete for 1914 than for 1915. The centres which increased their output in the former year were: Thio, Port Bouquet, Ny, Dumbea, Kopéto, Ouazanghou and Kalla. The new centres were Nakety and Camboui. There was a falling off in production at the following centres: Poro, Canala, Uie bay, Mont Do, Koné, Koniambo, Kaféate and Port Boise.

The estimated quantity of nickel ore at the mouth of the mines and at the smelters on 31st December, 1914, was 98,168 tons.

With the exception of the ore from Mont Do, which is said to have been mined by a subsidiary of Krupp's and sent to Germany, the other shipments went practically all to plants controlled by La Société le Nickel in England, France and Germany, and to the plant, near Antwerp, of La Société des Hauts-Fourneaux de Nouméa (Ballande). The last-named company has a refinery at New Brunswick, N.J., to which it has made all its shipments, chiefly matte, since the beginning of the war. Prior to the war the matte of this company from New Caledonia was sent to Antwerp. It was there further treated to bring up the percentage of nickel and a part of it sent to the New Jersey plant.

Return Showing Countries to Which Nickel Products Were Exported from New Caledonia During the Years 1912-14.[1]

To	Nickel Ore			Nickel Matte		
	1912	1913	1914	1912	1913	1914
	Tons	Tons	Tons	Tons	Tons	Tons
United Kingdom	44,638	31,862	44,426	....	1,500	2,494
France	3,251	14,000	23,380	1,731	993	....
Belgium	12,996	17,847	16,346	2,997	3,309	2,457
Netherlands	....	2,220	....	....	....	....
Germany	13,423	7,906[2]	7,906	....	....	....
United States	....	....	....	....	....	305
Australia	....	95	96	368	....	....

Value of Ore and Matte Exported in 1914.

To	Nickel Ore	Nickel Matte
	Francs	Francs
United Kingdom	1,263,768	1,754,138
France	700,794	....
Belgium	550,386	1,657,851
Germany	306,178	....
United States	....	213,578
Australia	2,894	....
Total	2,824,020	3,625,567

[1] These tables are taken from the British Diplomatic and Consular Report for the year 1914. Publication of this Report has ceased during the war. Ore sent to Australia and the Netherlands was en transit to other countries. In 1916, 3,000 tons of ore were shipped to Japan, where a refinery has been established.

[2] Figures for shipments to Germany in 1913 do not appear to be correct, but they are as given in the Consular Report.

Table Showing Producing Areas and Ports from Which Nickel Ore Was Shipped in the Years 1913-14.

Port of Exportation	Exportation Nickel Ore 1914	Exportation Nickel Ore 1913	Place of Production	Production Nickel Ore 1914	Production Nickel Ore 1913
	Tons[1]	Tons		Tons	Tons
Poro	6,420	12,588	Poro	29,605	29,950
Canala	3,050	....	Canala	3,014	4,914
Nakety	....	....	Nakety	1,211	....
Thio	45,507	28,160	Thio	50,643	48,011
Port—Bouquet	5,705	6,919	Port—Bouquet	10,124	9,665
Camboui	....	....	Camboui	184	....
Ny	....	....	Ny	1,661	1,369
Port—Boise	....	....	Port—Boise	....	8
Baie Uie	97	....	Baie Uie	2,000	2,495
Nouméa	....	2,318	Dumbea	7,013	6,713
Bouloupari	2,800	5,675	Mont Do	4,955	5,513
Pouembout	15,627	6,800	Kopéto	15,592	9,878
Koné	....	2,700	Koné	15,343	
Voh	9,970	16,742	Koniambo		42,619
			Kaféate	22,647	
Teoudie	2,206	8,814	Ouazanghou	4,573	1,700
Kaala—Karembe	2,772	2,474	Kaala	3,800	1,569
Totals	94,154	93,190*	Totals	172,365	164,404

[1] Metric tons of 2,204 lbs. each.

Composition of New Caledonia Ore

Analyses of New Caledonia nickel ores are based on the weight after drying at 100°C. Since the ores as mined contain 20 per cent. or more of uncombined water, what is called a 7 per cent. ore contains before drying only about 5.6 per cent. of nickel. As the ores are not dried before shipping, freight is paid on the large quantity of water as well as on the other constituents which they contain.

According to Glasser the following represents a composite or average analysis of the 7 per cent. ores after heating to 100°C.:—

Silica	42.
Magnesia	22.
Lime	0.10
Alumina	1.
Ferric oxide	15.
Nickel oxide	9.
Cobalt oxide	0.15
Manganese oxide	0.70
Chromic oxide	traces
Combined water	10.00
	99.95

The Commissioners have been furnished with the following table of analyses of ores from various mines. With the exception of the uncombined water, the analyses represent the compositions of the ores after drying at 100° C.

Selected Analyses of Types of Nickel Ores.

Name of Mine.	Situation.	Per cent H_2O dried at 100°C	Ni	Co	Fe	Al_2O_3	CaO	MgO	SiO_2	Loss on ignition.	Cr_2O_3
Fathma	Poro, East Coast	?	6.51—(Ni	& Co)	9.32	1.20	traces	16.36	49.60	?	?
Houailou	" "	?	4.84	....	10.63	0.52	"	22.16	45.64	10.78	1.40
Circé	Between Thio and Nakéty	?	6.97	....	10.20	1.27	"	17.40	50.62	?	?
Elise	Thio	26.61	6.80	....	11.92	1.30	"	19.30	38.52	?	?
Prises Alma & Rivoa	Port Bouquet E. Coast	22.86	6.46	0.13	12.81	0.20	"	24.95	36.82	?	1.20
" "	" " "	23.79	6.77	0.10	12.21	0.62	"	26.30	34.72	?	1.20
Puy. de Dome & Lucie	S. " "	?	6.47—(Ni	& Co)	Fe_2O_3 & Al_2O_3 =	16.79	?	27.89	35.78	12.09	*
Etoile du Nord	Massif Kaala. W. Coast	22.53	6.82—(Ni	& Co)	12.51	0.63	......	22.39	38.74	....	*
Nouvelle-Espérance	Massif Ouazangou W. Coast	26.50	6.78—(Ni	& Co)	12.27	1.42	......	23.19	39.76	....	*
Mines de Voh	Massifs Katepahie & Koniambo	22.60	6.67	0.13	13.83	0.77	......	21.11	42.10	....	*
Kataviti	West Coast	23.91	6.19	0.10	9.10	0.73	......	24.18	41.20	....	1.24
"	"	24.00	5.71	0.12	9.95	0.77	......	23.91	45.88	....	*
Annie	Massif du Kongouhiou	?	7.74—(Ni	& Co)	12.18	0.73	......	18.02	47.79	....	*
Souza	Region Dumbéa	?	5.45	?	12.65	1.42	......	23.26	38.56	....	*
Monnaie	" "	?	4.68	?	9.44	{ 1.07	......	{ 20.43	46.69	9.08	0.60
						{ 1.10	......	{ 18.90	49.98	9.30	0.57
Gracieuse	" "	27.50	7.26	0.15	11.10	0.41	......	27.03	36.90	8.95	1.38
Le Pic	" "	26.04	6.35	0.11	12.59	1.24	0.08	24.21	37.75	10.30	0.60
Barbouilleurs	" "	?	6.67—(Ni	& Co)	13.58	1.17	......	15.40	48.60	....	*
Tip Top	" "	?	4.75—(Ni	& Co)	12.38	1.28	......	29.43	35.11	10.23	1.47
Tamanou	Uié bay, S. of Island	?	5.92—(Ni	& Co)	{ 11.15	{ 0.59	......	{ 27.38	34.73	14.10	....
					{ 11.55	{ 0.59	......	{ 28.51	34.59	16.02	....

* Comprised in silica

Cost of Refining Nickel from New Caledonia Ores

The only official statement available regarding the cost of refining nickel from New Caledonia ores is contained in the report by Glasser to the French Minister of the Colonies, published in 1904.

This cost, while a little higher than estimates obtained from other sources of the cost at present, is, for all practical purposes, about the same. While costs may have been lowered somewhat during late years owing to mechanical improvements in plants and to smelting on the island, they have been increased in other ways; the cost both of labour and supplies has increased. During the war freight and other charges are abnormally high.

The following is a free translation of Glasser's Summary, pages 205-207:—

Nickel ores that are mined in New Caledonia are sent for the most part to Havre, Glasgow, or Rotterdam; in the immediate vicinity of the first two ports are plants which belong to the Société le Nickel. The plants at Havre and at Kirkintilloch have each produced during late years from 1,500 to 1,800 tons of nickel annually; from Rotterdam the ores are sent to Germany where they are treated, the production there of refined nickel being from 1,000 to 1,200 tons per year. Recently, in 1901, there have been shipped to America about 30,000 tons of ore.

The freight charges to Europe naturally vary with conditions in general, depending upon the charges elsewhere in the world, they oscillate usually between 30 and 40 francs per ton, a price to which it is necessary to add an insurance charge of 3 per cent. *ad valorem*. This freight charge is that which is made by French sailing ships, carrying from 3,000 to 4,000 tons of ores, which come from Europe to New Caledonia by the Cape of Good Hope and return to Europe by Cape Horn, making a voyage of about seven months in length, the ore frequently serving as ballast. Ships make on a voyage, outside the freight which they carry, between 100,000 and 150,000 francs, the bonus given to navigation by the French Government, a bonus which amounts on an average to about 125,000 francs per voyage and which covers nearly the whole cost of the voyage. According to the information which we have been able to obtain, the ships would not be able to accept freight at less than 50 francs per ton if a bonus were not allowed them; English ships which are not thus bonused will sometimes take freight at 40 francs.

We thus see that the freight represents a cost of from 48 to 55 francs per ton of dry ore, which would correspond to 70 or 75 centimes per kilogram of metal, thus doubling on arrival in Europe the cost of the nickel ore shipped (*i.e.*, the cost of freight represents about the same as the cost of the ore landed on board at New Caledonia).

The treatment of the ore in Europe consists of fusion to matte in a water-jacketed-furnace. In smelting, the ore is mixed with 20 per cent. of limestone and 10 per cent. of gypsum (or a quantity of soda ash containing an equivalent in sulphur) and 37½ per cent. coke. The resulting matte contains about 45 per cent. nickel, 40 per cent. iron and 15 per cent. sulphur; the silica, lime, magnesia and other materials pass into the slag, carrying with them only a small quantity of nickel. This matte is then converted, and the product is about 75 per cent. nickel, less than 1 per cent. iron and 24 per cent. sulphur; this high-grade matte is reduced

to a fine powder and roasted to remove the sulphur; the oxidized product is then reduced by carbon (flour, meal and other material being used to make a paste to mould the oxide into cubes, etc.)

We have not been given the exact cost of this treatment. We believe, however, that it does not exceed one franc per kilogram of metal produced; a half of these costs is represented by the first fusion.

Refined nickel is sold in Europe, depending on the state of the market, etc., at between 3.50 and 4 francs per kilogram. It might be added that the nickel which is extracted from New Caledonia ores by the process that has been indicated is very pure; it contains 99 to 99.5 per cent. nickel; it is freed so completely from the sulphur that has been added by the first fusion that it holds less than 1/1000 part; it is freed from arsenic and phosphorus and contains only a trace, less than 1/1000, of copper, which is introduced in treatment but which is not contained in the New Caledonia ore.

It will be noted that Glasser puts the cost per kilogram of metal at approximately 70 to 75 centimes f.o.b. New Caledonia, and he gives the same cost for freight to Europe, or say a total cost landed in Europe of 140 to 150 centimes per kilogram of metal. Then he says that he has reason to believe that the cost of smelting and refining does not exceed one franc per kilogram, half of this being represented by the first fusion, or in the making of the low-grade matte. This would make the cost of refined nickel between 19 and 20 cents a pound. From what is said on a following page it will be seen that the cost at the present time is about the same.

Character and Modes of Occurrence of Ores

Before discussing the methods of mining employed in New Caledonia, a few notes may be added, in addition to what has already been said, concerning the nickel ores and the serpentine with which they are associated and from which they have been derived. The serpentine represents the product of weathering of various basic rocks, under tropical or sub-tropical conditions in a country in which there is considerable rainfall. The total denudation of the surface of the island, since the intrusion of the rocks that have been altered to serpentine, is not known. That it has been great is evident from the appearance of the present surface. Among the serpentine masses themselves there are mountains, in the case of Mt. Humboldt, which reach to a height of over 5,000 feet, together with valleys and low lands that are at sea level or project beneath the water.

Over much of this weathered and denuded surface, which of course has not been glaciated like that of Ontario, loose products of decomposition of the serpentine are found, among which occur, here and there, deposits that contain sufficient nickel to make them of economic importance. Although the serpentine occupies about one-third the surface of the island, areas of considerable extent of this rock are without nickel deposits. Few deposits are found at as low an altitude as 400 feet and none at the highest elevations. Moreover, they are confined largely to the spurs of the mountains.

Various writers have attempted to classify the workable nickel deposits, but this can be done only in a general way. The variation in the character of the deposits is due to differences in the steepness of the surfaces on which they lie, to

differences in the breaking up of the weathered surface of the serpentine into blocks or fragments of various sizes, and to the presence or absence of distinct fissures and joints or other cracks in the serpentine. Where a surface is fairly steep there is more of a tendency for water to sort the loose products of weathering than there is on a flatter surface. Moreover, on a steeper surface waters tend to take the nickel dissolved out of the rock and carry it downward a considerable distance before it is deposited. Where fissures occur in the rock nickel tends to become concentrated in them. The absence of workable nickel ores on the Tiebaghi plateau, which has a considerable thickness of iron oxides and other decomposition products, and their presence on the faces of many hills and mountains, illustrate the statement as to the influence the characters of surfaces have on ore concentration. Another instance that may be cited is in connection with the iron deposits of

A New Caledonia Nickel Mine.

Cuba, that lie on the surface of serpentine but associated with which no deposits workable for nickel alone have been found. Nickel occurs in these Cuban deposits in sufficient quantity to produce workable ores in the process of weathering, were the surfaces not plateau-like on the whole and therefore not suitable for concentration of nickel.

Glasser distinguishes four types of nickel deposits in New Caledonia, *viz.*, vein-like deposits, brecciated deposits, masses of altered serpentine impregnated with nickel and nickeliferous earths. But two or more of these classes usually occur in the same workings. In the deposits first worked, much of the ore had the characteristic green colour of garnerite, the nickel-bearing mineral, but most of the ore now produced is the well known "chocolate" variety, the colour being due to oxides of iron.

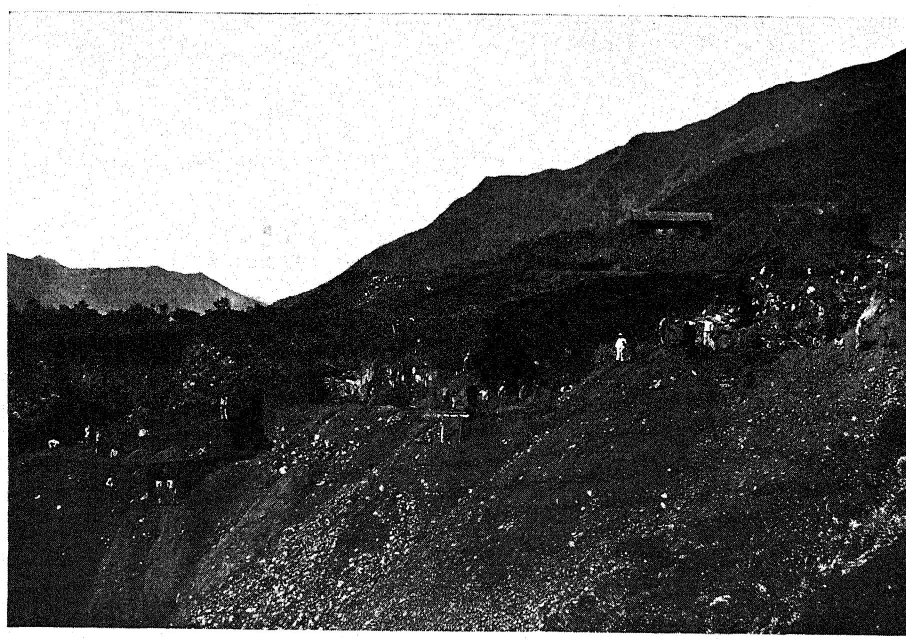
Ore Reserves and Competition

Statistical tables on other pages of this Report show the part that New Caledonia plays in the world's production of nickel. Controlling the world's markets at the time of Ontario's advent as a producer, New Caledonia has not

kept pace with her younger rival, although having the financial support of the house of Rothschilds, together with the accumulated experience, gained both before and after the discovery of the Sudbury deposits, and a tied market with a number of the greatest steel makers of Britain, France, and Germany.

The chief factor that has enabled Sudbury to outdistance her rival is the difference in the size of the ore bodies in the two countries. The greater of the Ontario deposits contain ore that is measured in terms of millions of tons, while those of New Caledonia are reckoned in a few hundreds of thousands, the greatest of her deposits having contained about 600,000 tons; few reach 250,000.

A determination of the ore reserves in New Caledonia is not possible owing to their uncertain character, but it might be fair to say that the colony possesses at least as much undeveloped ore of the same grade as she has already mined, in the



Nickel Mine at Dumbéa.

forty years of her existence as a producer, or say 160,000 tons of metal, a little over four years' output of Sudbury at the present rate of production. There are large quantities of lower grade ores which it has not yet been found feasible to treat.

The first mines to be worked in New Caledonia, there being many deposits to choose from, were naturally those that were the most accessible, usually those near some harbour. Many deposits that were once worked are now abandoned, including the Bornet mine near Thio, which has the record of having been the largest producer. The production of others of the larger mines is decreasing and new mines, such as the Emma, in more inaccessible situations are being opened up, necessitating the extension of the railways farther into the interior of the island. There is no evidence to show that any of the new mines are larger than certain of the old ones or that ore can be produced more cheaply from them.

The pith of the whole matter in so far as New Caledonia is concerned is the cost of refined nickel produced from her ores. More than a dozen years ago the cost was approximately 19 cents. Immediately prior to the present war it had not been lowered. To-day, with excessive freight rates and higher prices for supplies, the cost is much increased.

While prices of nickel remain about the same as they have been during recent years, New Caledonia will have an important industry. It will probably expand somewhat, owing especially to the activities of the newer of the two companies that are shipping ore and smelting on the island, but there is no reason for believing that competition with the Ontario industry will become any stronger than it has been in the past. Should the price of nickel fall to say twenty-five cents a pound or less, New Caledonia will have difficulty in keeping her mines in operation. But no right-thinking man will wish to see any French industry crushed or crippled.

A description of mining, smelting and refining as they concern New Caledonia, together with costs of the various processes, will be found on following pages.

The following table shows, approximately, the quantities of refined nickel produced from the ores of Ontario and New Caledonia at periods of five years, 1890 to 1910, together with those of 1913 and 1915. It illustrates the relative growth of the industry in the two countries, mining having begun in the former in 1886 and in the latter in 1875.

	1890	1895	1900	1905	1910	1913	1915
Ontario . ...tons	1,780[1]	2,316	3,540	9,503	18,636	24,838	34,039
New Caledonia ....tons	2,160[1]	2,737	6,584	6,627[2]	5,237	4,929	2,569

The largest and most important owners of nickel-holding lands in New Caledonia, in relative order of the importance of their holdings, are: (1) La Société le Nickel, a company which has been mining in the island for many years. (2) The International Nickel Company, represented in New Caledonia by its two subsidiary companies, The Nickel Corporation and La Société Miniere Caledonienne. The International does not mine in the island, but some of its lands are worked on lease by persons associated with Le Nickel. (3) Les Hauts-Fourneaux de Nouméa (Ballande). This company, much younger than Le Nickel, like the latter, mines and smelts part of its ore on the island. Since the beginning of the war it has shipped little ore, but is increasing its smelting capacity.

Methods of Mining*

The ore, nouméaite or garnierite, occurs as a hydrated silicate of nickel and magnesia and may best be described as an alteration product of the serpentine in which the magnesia and iron has been replaced by nickel. The ore formed by the replacement of magnesia by the oxide of nickel is termed "chocolate ore," and the replacement of the iron oxides by nickel oxide is known as "green ore." This alteration or replacement does not extend more than 25 feet to 35 feet on an average, in so far as workable ore is concerned.

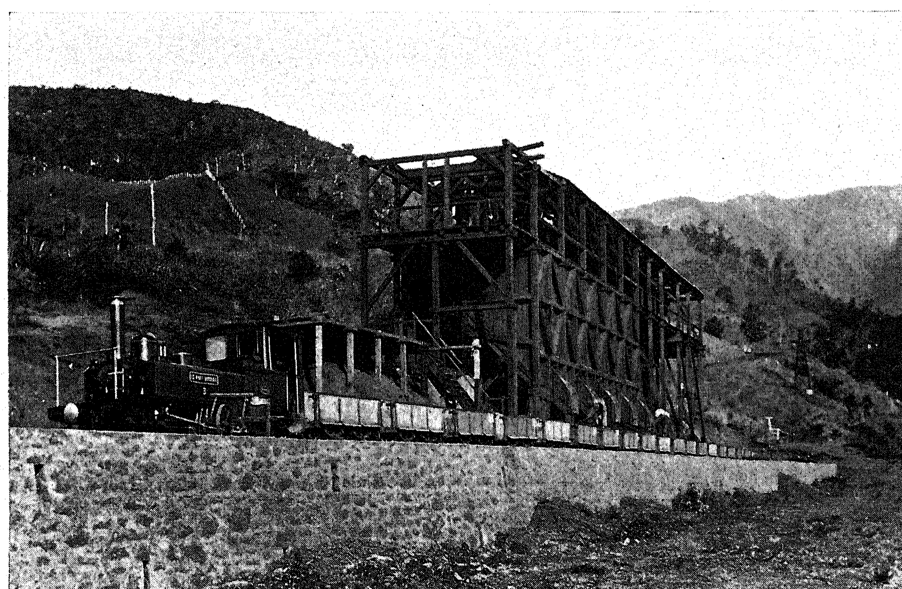
[1] Tons of 2,000 lbs.

[2] It is assumed that ore shipped in this and succeeding years averaged 4 8 per cent. of nickel in the wet ore and 45 per cent. of nickel in the matte. Ores shipped during recent years average 6 to 6.25 of nickel after being dehydrated at 100° C., or say 4.8 wet.

* The following description of mining in New Caledonia and data on the cost of refined nickel are by Mr. T. F. Sutherland, Chief Inspector of Mines for Ontario, who accompanied one of the Commissioners to the colony in 1916.

In appearance most of the ore resembles a brownish yellow clay, has a specific gravity and hardness of 2.5 and carries from 10 to 25 per cent. of uncombined moisture. The workable deposits always occur on the saddle of spurs from the main mountain ridge, at elevations of from 400 to 2,500 feet, the latter elevation being the more common. The ores are overlain by soil, barren decomposed serpentine or a pisolitic iron varying in depth from a foot or two to 15 or 20 feet, and in some cases up to 75 or 100 feet. The ores are generally richer on the upper part of the deposit.

The replacement of the serpentine by nickel follows the joints and fractures in the serpentine and the undecomposed blocks and boulders of serpentine are as a rule covered by a shell of ore which has to be picked off.



Loading Station and Aerial Tram.

Owing to this mode of occurrence of the ore, underground methods of mining are not attempted. The overburden is removed and the ore quarried out. Many properties in former days were worked by contractors. These men sold their ore to the large companies on a graduated scale depending on the nickel content. This scale was such that to make any profit ore carrying 7 or 8 per cent. of nickel had to be obtained. No attempt was made by these men to systematically open up a mine. They simply dug out any patches of high grade ore they found. In later years these properties have been acquired by large companies, but much ore was either lost or made unavailable by the early methods of mining. Ore is now bought on the following basis:—

6	per cent. ore (dry)	50 centimes[1] per kilo[2] of nickel
6½	" " " "	55 " " " "
7	" " " "	60 " " " "
7½	" " " "	65 " " " "

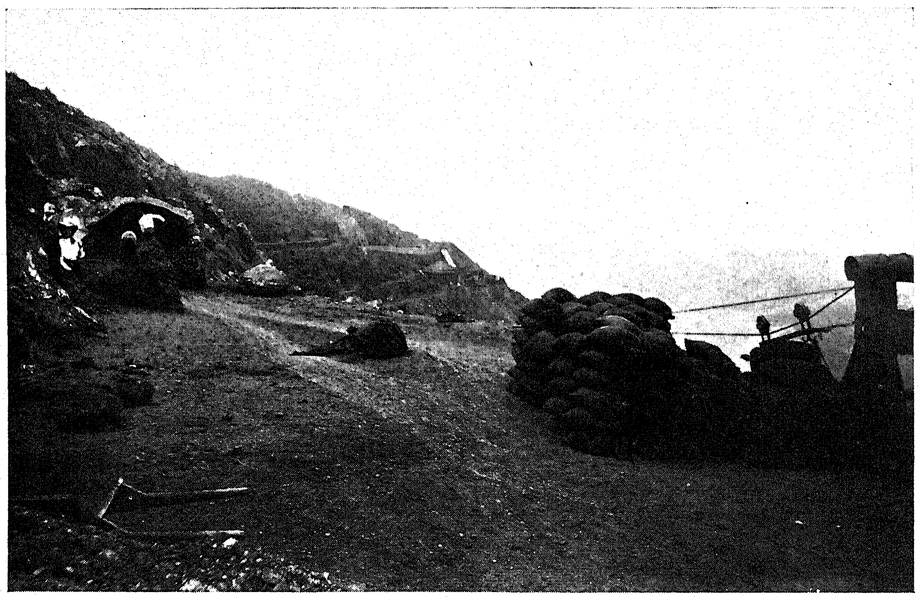
[1] 9.65 cts. [2] 2.2 lbs.

The mining practice at present is as follows: Where surface indications of ore are found prospecting pits are dug into the hillside, and if a good grade of ore is discovered without too great an overburden, a series of pits are dug across and along the slope to define the extent of the ore occurrence. If the overburden is over 9 feet in thickness and the grade of ore below 5 per cent. of nickel the prospect is not considered favourably. If the preliminary work shows an ore occurrence of sufficient tonnage and grade to be profitably worked, 25-foot contour lines are run along the hillside. These lines are graded out and are called levels. Tracks are laid and mining commences. The overburden for a few feet back is removed, loaded into cars and trammed to the dump. The ore is then picked or barred down and carefully sorted. The shell of ore around the boulders or blocks of serpentine is picked off, the waste trammed to the dump and the ore carefully gathered into

Transporting Ore by Horse Tram.

piles and sampled. This procedure is repeated until the face becomes too low grade to pay. Occasionally it is necessary to drill and blast the harder portions of the serpentine and for this work hand steel is used. Large blocks of low grade ore or waste are worked around and left standing on the bench. The ore is gathered from the different levels into a central loading station and transported from the mine to the foot of the mountains by aerial tram. The only equipment at the mine is the ore cars, tracks, picks and shovels and a few wheel barrows. If the mines are near the sea the aerial tram may discharge direct into stock piles, but generally a narrow gauge railway is built from the shipping port up a river valley and the aerial trams discharge into loading bins built along the railroad. At the shipping front the ore is stock-piled until there is a sufficient tonnage for shipment.

One noticeable feature of the nickel mining in New Caledonia is the extreme care used in sorting and sampling the ore. After the overburden is removed the floor of the quarry is swept clean before the ore is picked or barred down. Then any large pieces of ore are broken by hammers to a 2 inch ring and carefully sorted by hand. In some cases the fines are screened. The shell of ore on the boulders of undecomposed serpentine is chipped off as completely as possible with sharp picks, the waste is trammed to the dump, and the ore is swept up and gathered into 10-ton lots which are carefully sampled. The result of the assay is marked on each lot. In this way ore of a certain grade can be shipped. The necessity for this extreme care is due to the fact that the ore is not uniform in grade, that it is impossible to judge closely the grade of ore by appearance, and that in the past it has not been considered economical to smelt ore of a lower grade than 4.5 per cent. nor to ship ore of a much lower grade than 6.5. The average content in nickel of the



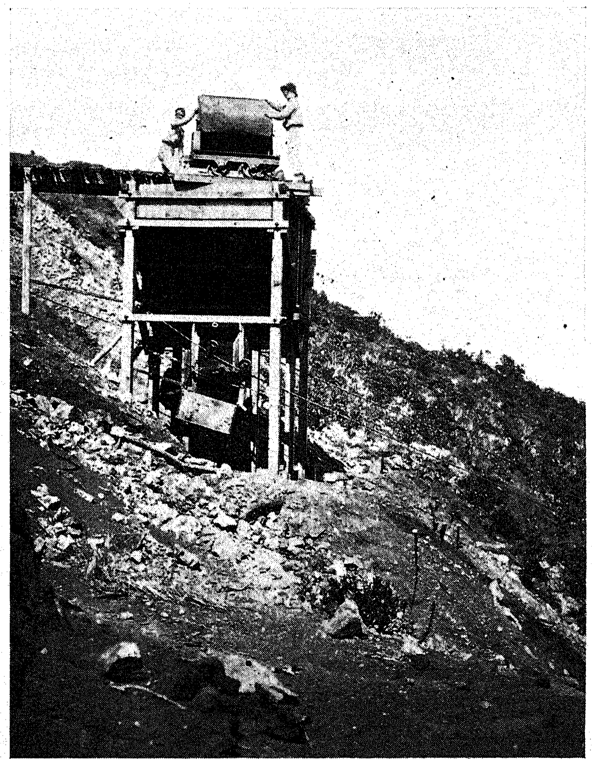
Sacks of Ore at Upper Terminal of Aerial Tram.

ore shipped in the three years 1913-14-15 was between 6 and 6.25 per cent., some shipments being above and others below this percentage.

As regards mining costs there is a wide variation depending upon the location of the property, the tonnage of the ore bodies, the amount of overburden to be removed, the grade of ore and the amount of sorting necessary to obtain a shipping grade of ore. On the location of the property depends the amount of capital expenditure necessary to provide transportation facilities, aerial tram and railroad to shipping front or smelter, and the tonnage and grade of ore will decide whether such an expenditure is justified or not. As a rule it may be said that the individual deposits are small, under 100,000 tons, and the largest mine yet worked produced under 600,000 tons.[1] A group of properties is often served by the one aerial tram,

[1] Metric tons of 2,204 lbs. each.

aided by branch lines and surface trams, while several such groups may be served by the one railroad. The amount of overburden to be removed has often prevented the working of an otherwise favourable prospect, though after the property is once operating it has been found economical to remove a considerable depth of overburden; in one case 72 feet of ferruginous earth overlying a good grade of ore was removed. The sorting necessary is generally from 8 to 10 tons of waste to one of ore, and 27 francs ($5.21) per ton (2,204 lbs.) of ore landed at the shipping front can be taken as a fair average of the mining costs.



Loading Station at Mine.

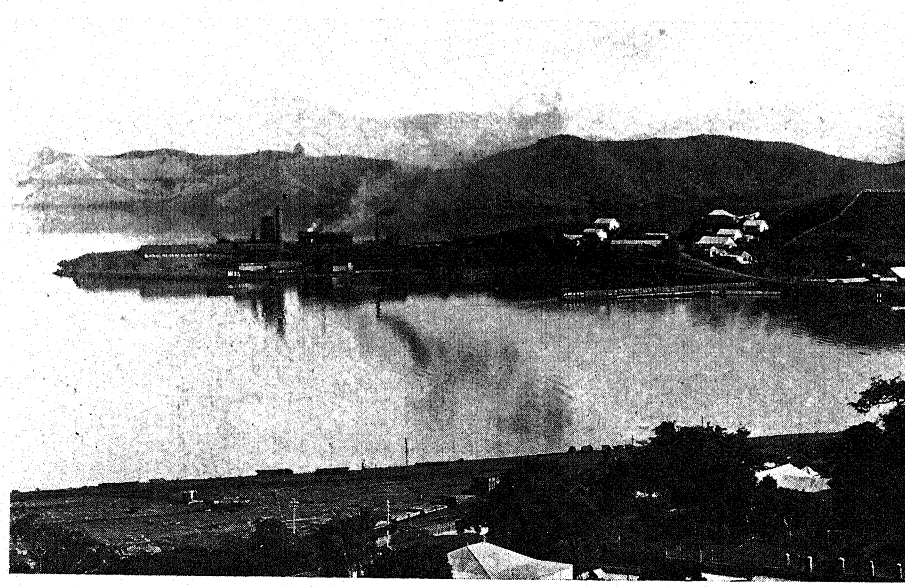
Smelting

The first attempt to smelt New Caledonia nickel ores on the island was made in the year 1879, when two furnaces were erected at Nouméa. A 9 per cent. ore was treated and a "fonte" made containing about 65 per cent. of nickel. Fifteen and one-half tons of ore were treated daily. The charge consisted of one ton of ore and 450 kilos of limestone and a 49 per cent. coke charge. The smelting costs amounted to about 85 francs per ton of ore, or about 95 centimes per kilo of nickel (or 8.3 cts. per lb.).

As it was found to be impossible to bessemerize this fonte, necessitating a second operation in which the fonte was sulphurized, this method of smelting was abandoned and the furnaces were used to make a matte, the charge consisting of

1,000 parts of ore, 385 parts limestone and 72 parts gypsum. About 20 tons of ore were smelted per day, producing a little less than 3 tons of matte averaging 62 per cent. of nickel. This change reduced the smelting costs to about 76 francs per ton of ore, or 85 centimes per kilo of nickel (7.4 cts. per lb.).

The next step in the metallurgy of New Caledonia nickel ores was cupola smelting. The cupolas were water-jacketed, with inside diameter of 5 feet. The first cost of these furnaces was small, but they required constant attention, and owing to the shallowness of the charge, height of charge from tuyeres being only 3 feet, much heat was lost, and there was a smelting loss of 11 per cent. in fine dust being carried off by the blast. The slag loss was not great, being only 0.3 per cent. nickel, but the slags had to be kept constant. The coke consumption was about 33 per cent. In operation the ore was mixed with coal dust, 75 per cent. of the necessary limestone, and the right percentage of sulphur, about 2½ per cent.,



Nickel Smelter at Nouméa.

briquetted and charged into the furnace. The remainder of the limestone was distributed loosely over the charge together with slags, etc. One advantage was that a lower grade ore could be utilized, down to 6 per cent. of nickel. The cost was about 30 francs per ton of ore smelted, or 65 centimes per kilo of nickel (5.7 cts. per lb.), after allowing for the smelting loss.

Present day smelting practice is to replace the cupola furnaces with modern water-jacketed blast furnaces. The two large operating companies, Sociéte le Nickel and Société Hauts-Fourneaux de Nouméa, operate smelting works, the former at Thio and the latter at Nouméa. The capacity of each works is from 100 to 120 tons of ore per day, producing about 9 tons of matte carrying from 40 to 46 per cent. of nickel, ore assaying as low as 4½ per cent. of nickel being used. A small quantity of ore has also been smelted in an electric furnace by the former company at Tao.

Le Nickel's matte is said to carry 45-48 per cent. of nickel and that of the other company 42-45. The former company smelted 20,000 tons of ore in 1913, the same quantity in 1914, and 29,000 in 1915; the latter company smelted 20,000, 22,000 and 35,000 respectively in these years.

The ores are delivered to the smelters by rail or water transportation and stock-piled under sheds to be kept dry, the sun dried ore carrying from 5 to 11 per cent. of uncombined water, while, if not protected, in wet weather the moisture will approach 25 per cent. Ores from different sections are kept separate and will vary in silica content from 35 to 50 per cent. The different grades are mixed before briquetting and this material is fed into pug mills with the necessary quantity of gypsum and some flue dust added. The pug mills discharge into briquetting machines. The briquettes which weigh 2½ kilos (5½ lbs.) are then stored in

Smelter Yard at Thio.

drying sheds, where they are allowed to dry and harden. The furnaces are charged in the ordinary manner, the limestone or coral being added with the coke and also any fluorspar or slags that may be necessary for the free working of the furnace. A 30 per cent. coke charge is used.

The ores, briquettes and slags on analysis show about the following composition:

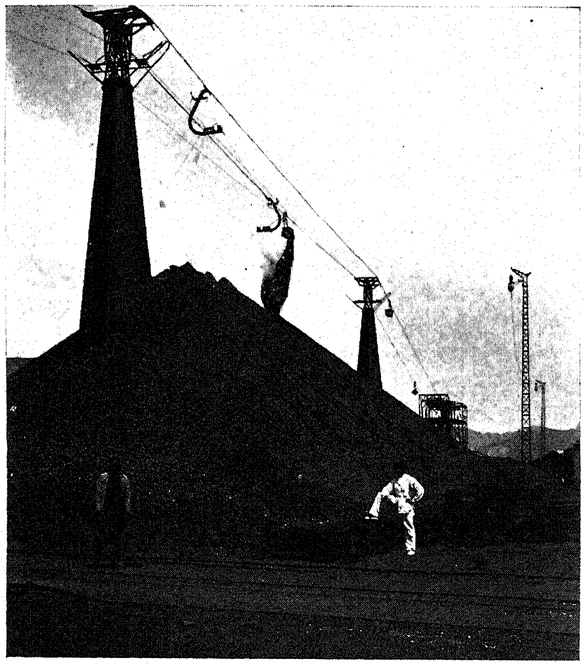
	SiO_2	Al_2O_3	FeO	Fe_2O_3	MgO	CaO	SO_3	H_2O
Ore	41-52	...	...	9-19	20-22	...	...	8-11
Briquettes	37-40	3-5	...	11-15	18-20	3-5	5-7	10-12
Slag	45-50	8-12	10-12	...	17-22	9-14	...	...

Limestone, gypsum, fluorspar and coke and coal necessary in the smelting operations have to be imported. The New Caledonian limestones are only of medium quality and are often high in silica due to quartz stringers. At the present

time, 1916, due to the high ocean freight rates, it has been found economical to use coral. Analyses of New Caledonian limestone and coral are as follows:—

	SiO_2	$CaCO_3$	$MgCO_3$	Fe_2O_3	H_2O
Limestone	17.05	78.15	1.46	2.70	....
Coral	3.30	77.70	8.20	3.80	4.35

Gypsum was formerly imported from France, being carried out as ballast by sailing ships in the ore carrying trade, but at the present time the supply is imported from Australia. The price is 20 shillings per ton f.o.b. Port Marian, South Australia, and about 36 shillings per ton f.o.b. Newcastle, Australia. The gypsum must grade 16 per cent. sulphur. Freight from Australia to New Caledonia at the present time is from 20 shillings to 40 shillings per ton. The New Caledonian gypsum costs just about as much as the Australian gypsum landed at the smelters,



Ore Carrier, Aerial Tram.

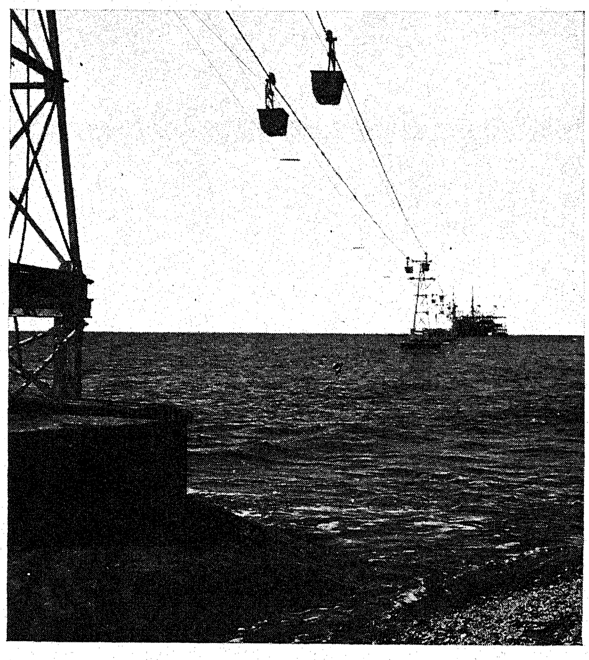
as it has to be hand-sorted in order to get a suitable grade. Coal and coke before the war were brought out by the ore ships from France and England, but are now obtained from the Newcastle district, Australia. A coke analysis gave:—

Volatile matter 0.46, fixed carbon 90.88, ash 7.93, sulphur 0.42, water 0.31. An ash analysis gave: Silica 51.20, lead 0.70, alumina 34.30.

The price of coal f.o.b. Newcastle, Australia, is 12 shillings per ton and of coke 15 to 20 shillings per ton, depending on the quality. Before the war, freight on coal from Newcastle to New Caledonia was 10 shillings per ton. Coke freights are 50 per cent. higher than coal freights. Some fluorspar is used in smelting operations in order to obtain a more fluid slag. This is imported from Australia, where it costs 100 shillings a ton, only 10 tons being imported in the five months preceding September, 1916.

Transportation

The shipment of ore or matte to foreign markets, or the transportation of the ore from the loading port to the smelters, is a serious and expensive problem with which the operating companies have to contend. The island is surrounded by a coral reef, and within this reef is a fairly safe anchorage for vessels except during the hurricane season, December to March, inclusive. Very few of the mines happen to be situated adjacent to good harbours, and it is necessary for the shipping to anchor a considerable distance off shore. Incoming material has to be discharged into lighters, which are towed ashore, and ore and matte have to be shipped out the same way. Windy weather which will not endanger the ship at anchor still makes it impossible to tow the heavily laden lighters back and forward between the shore and ship, and much time is lost. A small dock is generally



Marine Terminal at Thio.

built at the loading front so that the ore can be trammed in cars from the stock pile and dumped direct into the lighters. At the ship the ore has to be loaded into buckets by hand. The docks at the smelting works at Thio and Nouméa are equipped with locomotive cranes to assist in unloading the ore or fluxes from the lighters.

At Thio a marine terminal was built, one kilometre (1,093.6 yds.) from the shore and connected with the shore by a Bleichert aerial ropeway, but this loading terminal was partly destroyed by a hurricane and the company have reverted to lighters for loading and unloading ships.

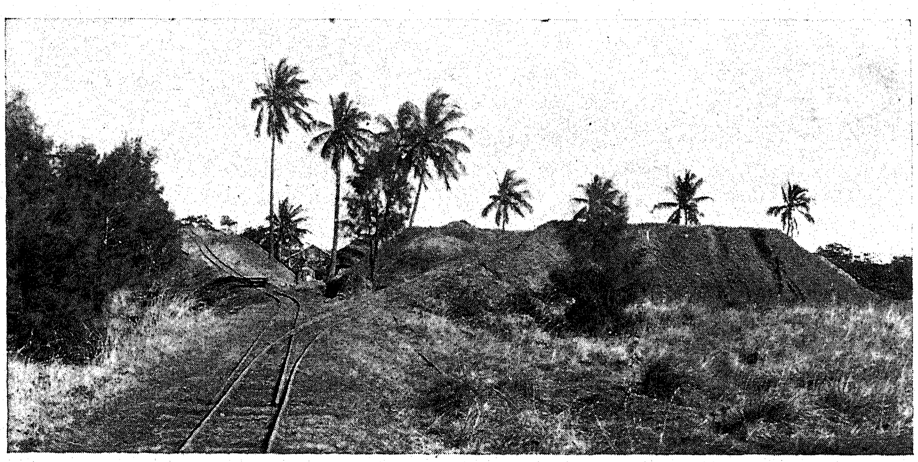
The cost of loading ore on ship, transporting to smelter and unloading may be put at 8 francs a ton.

Before the war freights on nickel ore in bulk per ton of 2,240 lbs. from Nouméa to Hamburg were from 21 shillings in 1908 to as high as 35 shillings in 1913. Freight on matte from Nouméa to Glasgow by Sydney was 40 shillings. Present freight rates, 1916, are 300 and 400 per cent. higher.

Labour

At the present time the principal labour employed at the mines is Japanese and Javanese, with a few natives from neighbouring islands. The New Caledonia native will not work at the mines.

When the nickel mines were first opened in 1876 convict labour was employed. The convicts were hired from the Government at a nominal sum, and as the mining



Stock Pile at Shipping Front, Kataviti.

was simply pick and shovel work in the open, this class of labour, while troublesome and inefficient, was still cheap. The importation of convicts to New Caledonia ceased in 1898, and at the present time only a few ex-convicts are employed by individual operators who sell ore to the larger companies. The majority of the workmen employed by the large companies are Japanese, and this class makes the most satisfactory labour that can be procured at the present time. They are imported under a three or a five year contract and are paid about 5 francs (96.5 cts.) a day. There are certain stipulations regarding food, housing, etc., and a Japanese representative is resident on the island who looks after the men's interests and acts as a medium in any disputes that arise between the men and the companies. Some Javanese are employed in actual mining and much of the domestic work is done by this nationality. Natives from the neighbouring islands are used around the shipping ports for lightering, etc. At the smelters many Arabs are employed where the heat is severe. Superintendents, foremen and many of the clerical staff are from France.

Mining Laws

Title to a mine is only acquired by concession, which gives the right to mine for, in their vertical dip, and to dispose of, the substances named in the concession. Minerals which may be acquired by concession are divided into four classes:—

1. Combustibles, *i.e.*, petroleum, coal, etc.
2. Salts, nitrates, phosphates.
3. Nickel, chrome, cobalt, manganese and iron.
4. All other substances.

The concession to mine one mineral includes the right to mine all substances of the same class.

An annual rental of 40 centimes (7.32 cts.) per hectare (2.47 acres) is charged by the Government for prospecting areas and for concessions, until such time as the concession is opened up, when the following schedule of taxes applies:—

Class 1.

Francs.		
0.50	per hectare	up to 5,000 hectares.
0.74	do	from 5,001 to 10,000
1.00	do	over 10,000

Classes 2, 3, 4.

0.75	per hectare	up to 500 hectares.
1.00	do	from 501 to 1,000
1.25	do	from 1,001 to 2,000
1.50	do	from 2,001 to 5,000
1.75	do	from 5,001 to 10,000
2.00	do	from 10,001 to 15,000
2.50	do	from 15,001 to 20,000
3.00	do	from 20,001 to 30,000
3.50	do	from 30,001 to 40,000
4.00	do	over 40,000

A permit to prospect is obtained from the Government and gives the exclusive right to prospect a block of ground. The minimum for a prospecting area is 300 metres (327 yds.) square and the maximum 5 kilometres (3.1 miles) square, or 6,150.4 acres. The boundaries of such an area must run north and south and east and west. This permit is good for one year from the date of issue and is renewable.

If mineral is discovered the holder of a prospector's permit may apply for a concession; such concession must be in the form of a rectangle, the shorter side of which is not less than one-quarter the length of the longer side, and such concession must be entirely within the prospecting area held under permit. The concession must not be greater than 2,500 hectares nor less than 100 hectares for Class I., and a maximum of 2,000 hectares with a minimum of 5 hectares for the 2nd and 3rd and 4th classes.

Mining rights cannot be subdivided without the authority of the Department and can only be transferred with the consent of the Department. Concessions which are not worked or sufficiently exploited after a period of five years are subject to a special tax. By "sufficiently exploited" is meant a production of one ton of nickel per hectare per year, one-half ton of chrome iron per hectare per year, 125 kilograms of cobalt per hectare per year, one ton of copper per hectare per year, and for any other mineral four days' work per hectare per year.

Export Duty

The export duty on New Caledonia ores is 5 per cent. *ad valorem* per wet ton. Values are fixed half-yearly by the Government. For purposes of this tax the following values are assumed:—

	Tenor.	Value per wet ton. 1st half 1916.	Value per wet ton. 2nd half 1916.
Nickel	Up to 5.74 per cent.	22 francs	46 francs
"	5.75 to 5.99	31 "	54 "
"	6 to 6.24	37 "	60 "
"	6.25 to 6.49	41 "	65 "
"	6.50 to 6.74	46 "	79 "
Chrome	Up to 50 per cent.	37 "	40 "
"	Plus 2f50 per additional unit.		
Cobalt	Up to 4 per cent.	40 "	40 "
"	4 to 5 per cent.	50 "	50 "
"	5 to 6 per cent.	70 "	70 "
"	6 per cent. and over	90 "	90 "
Copper	Any grade	50 "	50 "
Phosphates	"	60 "	60 "
Antimony	15 to 29 per cent.	.. "	200 "
"	30 to 49 per cent.	.. "	400 "
"	50 per cent. and over	.. "	700 "

Shipments of any other mineral products, 5 francs per ton.

The export duty on ore, together with the cost of freight on water and other useless material contained in it, encourages the smelting to matte, which is free from export duty, on the island.

Cost of Refined Nickel

The cost of producing nickel from a 6 per cent. New Caledonia ore, before the war, was between 19 and 20 cents a pound. It is probable that under present conditions this cost is increased at least 20 per cent.

NORWAY

Prior to the advent of New Caledonia as a producer, Norway, where mining began in the forties, and reached its greatest importance in the period 1870-1877, controlled the nickel market. The total output of nickel ore between 1850 and 1893 is said to have been about 330,000 tons. The maximum of production was attained in 1876 with an output of 42,500 tons of ore containing 360 tons of nickel, conditions at that time permitting the smelting of ores with 0.9 to 1.5 per cent. of the metal.[1]

On a preceding page mention has been made of the effects of New Caledonia competition on the Norwegian industry, resulting in the closing of the mines. The introduction of the Hybinette electrolytic process of refining, together with an increased demand for nickel, has brought about the reopening of the mines during recent years. In addition to ores of local origin, comparatively small quantities of ores from Greece and elsewhere have been treated in the Norwegian plants. Most of the output has gone to Germany. Copper and precious metals, as well as nickel, are produced from the Norwegian ores. Statistics of production are given on another page.

[1] Beck, The Nature of Ore Deposits, Weed's translation, p. 38.

The richest nickel mine in Norway is, however, the above mentioned Flaad mine, which works an ore body occurring in a mass of uralite gabbro about 75 sq. km. in extent. The production so far, that is between 1872 and 1908, has been about 75,000 tons of ore, equivalent to 1,350 tons of nickel and 800 tons of copper. The present depth is about 90 m. [290 feet], though the ore body is far from exhausted to that depth. . . . Latterly only one mine, the Flaad, continues working. In the whole of Norway roughly 400,000 tons of nickel ore have been mined and smelted. The hand-sorted ore usually yields 1.4 to 1.7 per cent. of nickel, though exceptionally the yield may be as much as 2 to 2.5 per cent.[1]

The ore deposits of Norway are similar to those of Sudbury in mineralogical character, consisting essentially of pyrrhotite and chalcopyrite together with more or less pyrite and other minerals, and in the nature of the rocks, norite, associated with them. They are, however, small and contain comparatively low percentages of the metals. Considered as competitors with New Caledonia or Sudbury they are of little consequence.

Deposits of ore of the character mentioned have been found at various places not only in Norway but in Sweden as well. In the latter country the ores have not been worked during recent years.

In 1913 about 28,500 tons of ore from the Flaad mine, 2,000 from the Faeo and 2,000 tons of Grecian ore are said to have been smelted in the Evje plant. At the other smelter, the Ringerike, 13,000 tons of Ringerike ore and 1,250 tons purchased abroad were smelted.

At the Kristianssands refinery in that year there were received about 458 tons of nickel and 274 tons of copper in the form of matte from the Evje plant and about 207 tons of nickel and 118 tons of copper from the Ringerike plant. From this matte there was refined and shipped about 602 tons of nickel and 388 tons of copper. Shipments of precious metals obtained in the refining process were also made. In the same year arrangements were made to increase the capacity of the refinery to 1,200 tons a year of nickel, and to enlarge the smelters. In 1914 the production of nickel was 841 tons and in 1915, 793 tons.

BORNEO, ISLAND OF SEBOEKOE[2]

From the description it will be seen that the iron ores of this island are similar in character and mode of occurrence to those of Cuba, that contain nickel and chromium. They have had the same origin as the Cuban ores and the nickel-bearing ores of New Caledonia, the deposits of all three countries representing the weathered surface of serpentine. The situation of Seboekoe is shown on the map, page 234.

The following notes are taken almost verbatim from letters written by H. N. G. Cobbe to the Chairman of the Commission:

In the island of Seboekoe, lying off the southeast coast of Borneo, there exists a large surface deposit of porous limonite about 15 feet thick overlying serpentine. A great part of the deposit lies along and near the sea shore, facing the channel which divides the island from its larger neighbour, Laoet. The channel affords good anchorage. The deposit has been well prospected by pits and drill holes and extends for four miles parallel to the coast rising from the sea level to a hill in

[1] Beyschlag, Vogt and Krusch, Ore Deposits, 1909, Truscott's translation, p. 297.

[2] Having discussed the occurrences of the nickel ores of Sudbury, New Caledonia and Norway in preceding pages, those of other countries will now be dealt with in alphabetical order.

places 300 feet high. There is no over-burden but the deposit is to some extent grown over with timber.

The ore can be divided into two classes; the first class, from the surface to about 7 feet deep, is a little heavier and a little richer in iron and is more gravelly than the deeper-seated ore, and is of a reddish brown colour. The second class, about 8 feet in thickness, is more earthly in texture and is yellowish brown in colour.

Both classes of ore have nearly the same composition in the dry state. The upper layer contains about 40 per cent. "gravel," *i.e.*, material from ¼″ to 6″ or upwards, the remaining 60 per cent. being fine soft ore. The deposit contains at least 300,000,000 tons of porous limonite ore which, when dried, contains over 50 per cent. Fe, and when calcined over 60 per cent. Fe and about 0.5 per cent. Co and Ni.

The following is a table of analyses made on many samples taken and grouped as shown.

Separating Ni and Co in one sample, Ni=0.54, Co=0.08 (Dandurand, Paris).

MIXED ORE.	From Depth 0 to 6 ft.	From Depth 6 to 9 ft.	From Depth 9 to 15 ft.
CALCINED ORE.	Per Cent.	Per Cent.	Per Cent.
Fe	61.30	60.30	60.69
DRIED ORE.			
Fe	53.09	50.01	51.69
SiO_2	2.75	2.35	2.30
Mn	0.43	0.37	1.05
S (average 0.18 per cent.)	0.21	0.12	0.19
P	0.06	0.037	0.029
Cr	2.30	2.20	2.05
Co and Ni	0.39	0.41	0.45
Insolubles	4.95	5.45	5.50
	64.18	60.947	63.259

The island is a Dutch possession and the title is held direct from the Government under the mining act and is current for 75 years. The extent of the concession is 15,654 acres.

Apart from the favourable physical condition and situation of the ore, the property is well placed as regards fuel, limestone, aluminous flux, transport and the eastern market generally.

Mr. Cobbe quotes the following from the owner of the property:—

On this question of analysis I have the letter of the Director of the Society Francaise d'Etudes et d'Entreprises, who sent out the French expert Gascuel in 1906. He writes me the following concerning the sample taken by Gascuel himself:—

The average composition of the ore in chromium, nickel, sulphur, phosphorus and arsenic has been on 15 samples of the upper layer:—

	Per Cent.
Cr.	2.21
Ni.	1.00
S.	0.03
P.	0.04
As.	0.012

This analysis is by Campredon of Nantes.

Mr. Cobbe further says:—

I smelted some of the ore which I have in bags here, and which was taken indiscriminately from a cargo, and the resulting iron analyzed 1.2 and 1 26 nickel, which indicates the presence of that metal in the original ore in greater quantities than shown in the table.

The island of Seboekoe is about 20 miles long and 3 to 6 wide. It is practically uninhabited and well timbered. It lies no great distance to the south of one of the largest oil refineries in the East and is not more than 20 miles from a coal mine on the island of Laoet, owned by the Dutch government, who paid £360,000 (sterling) for it and who work it. The coal on Seboekoe is the same bed, which has been eroded between the islands.

The average temperature lies between 70 and 85 F., above which it seldom goes. There are no hurricanes, being situated almost on the Equator, and the steady S.E. winds do not raise any sea between the islands where the anchorages are.

There are many trade routes. Kota Barus is quite a place, and just across is the Dutch coal mine on the mainland. A route is easily induced in this part of the East, where there are 50 million souls. Macassar, to the S.E., is a great port, in direct service with Europe—Amsterdam, London and Hamburg—and steamers would call at Seboekoe and bunker coal or load pig at Seboekoe at (probably) Macassar rates. It is about a six shilling rate to Japan, and practically on the fair weather cargo route, England to Australia, via Singapore, from which it is no distance.

CUBA

The nickeliferous iron ores of the island of Cuba, in the districts of Mayari, Moa, and San Felipe or Cubitas, have attracted much attention during recent years. Several important papers descriptive of these ore fields have been published. An excellent paper by J. F. Kemp deals with the Mayari deposits, the only deposits that have yet been worked.[1] The following quotations are from this paper.

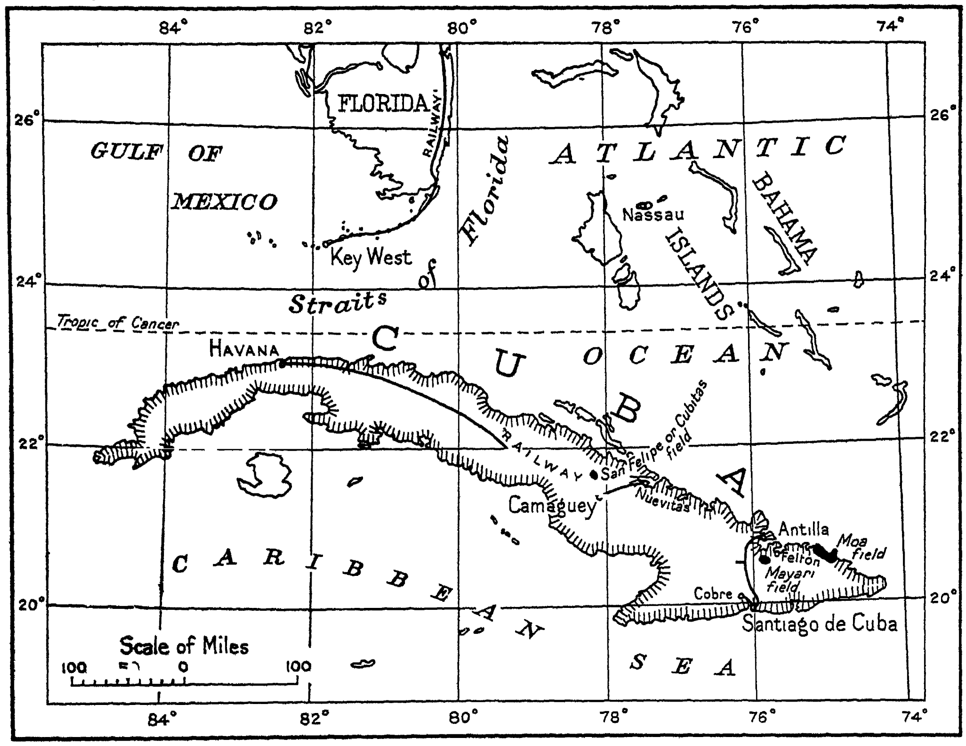
Crusts and concretionary masses of brown iron ore were early noted in northeastern Cuba. J. S. Cox, Jr., writing in 1911 ...., states that claims were located upon them in the Moa district more than 20 years earlier. A. C. Spencer remarked them in 1901 as appearing in red clay, but no one seems to have realized until three or four years later that the entire mass was high enough in iron to be an ore. Under J. S. Cox, Jr., explorations were begun in the Mayari district in 1904 upon the crusts or "plancha," and then analyses revealed the fact that not only the upper, dull-red portion of the so-called clay was valuable, but also the lower yellow parts as well. The construction of the Mayari plant of the Spanish-American Iron Co. was begun in 1907 and was completed in December, 1909. Shipments have been active ever since. The plant and mines were well described with maps and views by J. E. Little in 1911, ... The chief changes since then have been the greater extent of the pits on the plateau at Woodfred, and the improvements in the village of Felton, the shipping port on Nipe Bay. The ore is principally treated at Sparrows Point, Md., and Steelton, Pa. It is shipped both in the crude state and as so-called "nodulized ore," or the product of kilns similar to modern cement kilns, in which the water, both absorbed and combined, is driven off and the fine ore is half fused or fretted into nodules. Mushiness in the stack is thereby prevented and the rather heavy percentage of water (25 per cent. absorbed and 14 per cent. combined) is driven off, to the diminution of freight charges. Three or four per cent. of water is again absorbed in the cooling vats into which the kilns discharge. Analyses of the raw ore are customarily made on samples dried at or above 100°C. They have averaged by the year: Fe, 48 to 49; Ni, 1; SiO_2, about 3; Cr, 1 to 2; Al_2O_3, 11 to 11.5; combined H_2O, 13 to 13.5. The nodulized ore runs: Fe, 55 to 56; Ni, 1 to 1.2; SiO_2, 4 to 4.4; Cr_2O_3, slightly more than the raw ore; Al_2O_3, 13 to 14; absorbed water, 3 to 3.5. In both, sulphur and phosphorus are negligible. In time, the great purity of these ores, combined with their percentages in nickel, and their convenient shipment from deep-water docks, should win a European as well as an American market.

Geologists who have studied these Cuban iron-ore deposits are agreed as to their origin. The ores have been formed, like the New Caledonia nickel deposits,

[1] The Mayari Iron-Ore Deposits, Cuba, Am Inst M E., Vol. LI, 1915. This paper gives a list of earlier publications.

through the weathering of basic rock, now represented by serpentine, and rest practically on the surface of the rock from which they have been derived.

In the faces of the pits as now extensively exposed, the observer can readily note that there are three distinct layers: An upper, of crimson-brown hue; a middle one, yellowish brown, and a bottom layer of a lighter shade of yellowish brown. In one face, called the Three-Hill cut, the upper was noted at 5 to 6 ft.; the middle at 6 to 12 ft.; and the lower at 4 to 6 ft. . . . Analyses of each layer, but from another station, will be subsequently given. As distinct from these varieties the engineers in charge have noted that in the occasional and rather rare spots in the residual mantle where the iron percentage is too low for mining there appears at the surface a peculiar purple color, quite easily recognized and an indication of high alumina in the samples. The color appears to be due to the relatively rich admixture of normally white bauxite with a darker-hued brown iron ore. The explanation of the higher alumina is to be found in local changes in the original rock, as later set forth.



Map of Cuba.

In some places, at the surface or a few feet below it, slabs and even continuous sheets of solid iron hydrate appear and afford the cellular varieties of brown ore, very similar to the crusts and lumps long familiar in the mines of the Appalachian belt. As earlier stated, the solid ore is called plancha. In the residual mantle shots and larger lumps of solid brown ore are at times intermingled, chiefly in the upper, darker layer. The general run of the ore is, however, earthy, and reminiscent in the strongest degree, alike in color and texture, of the Mesabi ores The higher content of absorbed water, the higher alumina, and the lower silica of the Mayari ores give them perhaps a somewhat more spongy aspect than one notes on the Mesabi range; on the other hand, at Woodfred there is no overburden whatsoever, and the ore is obtained from grassroots to bedrock.

The recently mined ore has a peculiar mealy character, reminding one of nothing so much as dampened meal, but as it dries out this character disappears. No doubt the colloid nature of the hydrates of alumina and iron is the cause of the peculiarity.

The following analyses made by T. C. Kraemer, chemist of the Spanish-American Iron Co., were based upon samples gathered by the writer to illustrate the three contrasted layers The samples were taken as nearly as practicable in a vertical section

	I. Surface Ore. Sta. 11, 35, 10. Crimson-brown.	II. Middle Layer. Sta. 11, 35, 10+15. Yellow.	III. Bottom Layer. Sta. 11, 35, 11. Yellow.
SiO_2	2.26	2.70	7.54
Al_2O_3	14.90	7.13	4.97
Fe_2O_3	68.75	71.89	64.81
Cr_2O_3	1.89	3 17	3.66
FeO	0.77	1 29	1.49
NiO	0.74	1.60	2 75
MgO	....	....	1.50
H_2O (combined)	11.15	12.90	12.75
Total	100.46	100.68	99.47
Metallic iron	48.65	51.32	46.52
Metallic nickel	0.59	1 20	2.10
H_2O absorbed (a)	4.62	9.72	27.00

(a) Determinations of absorbed water based on original sample. Other determinations on dried sample at 110°C.

The following quotation is from a paper by J. S. Cox.[1]

The partial or complete elimination of the chromium and the production of a satisfactory steel were accomplished after patient experiment. Steel rails made from this ore have demonstrated their superiority over ordinary rails, by actual use on the Horseshoe Curve of the Pennsylvania railroad. For more than a year the Pennsylvania Steel Co. and the Maryland Steel Co. have manufactured commercially, from Mayari steel, a steel which, by reason of its nickel content and low phosphorus, is superior to ordinary Bessemer steel and open-hearth products.

In mining a selection may be made by removing first the upper part of the layer and then the lower, the latter containing a higher percentage of nickel. The average depth of ore mined is said to be about 19 ft. Costs, under normal conditions, of nodulized ore, delivered at Baltimore, are said to be about $2.50 per ton.

As to the extent of the deposits in the three fields A. C. Spencer says:—[2]

Mayari.—The ore deposit is a blanket formation, extending as a practically unbroken mantle over a gently rolling elevated plateau, roughly 10 miles long and 4 miles wide; or more accurately about 28,770 acres. Except for a few groups of hardwood trees in moist situations, the ore field is covered by pine forest, averaging about 40 trees of medium size to the acre. . . .

A fair average depth of ore over 18,525 acres is 15 feet, which, at 20 cubic feet to the ton, gives 605,000,000 tons.

Moa.—The deposit is very much like the one at Mayari. . . . The mantle of ore is a prominent feature within an area of about 60 square miles, being practically continuous, except where it has been cut by erosion along the stream valleys. It is roughly estimated that 60 per cent. of the area taken up, or about 36 square miles, will afford ore of mineable grade and quantity. . . . Taking the area of valuable ore at 36 square miles, and, as at Mayari, taking the average depth as only 15 feet, and allowing 20 cubic feet of material per ton of dried ore, we get 752,000,000 tons for a just approximation of the valuable tonnage of iron ore in the Moa field.

Cubitas.—The ore deposits are all surface mantles covering the plateau-like mesas. . . . It is thought that there must be at least 6,000 acres of the ore ground and that at least 150,000,000 tons of ore exist within the field.

[1] Am. Inst. M. E., Vol. XLII, 1911, p. 88.
[2] U. S. G. S. Bull. 340, p. 320.

Another estimate makes the total tonnage of the three areas about 3,000,000,000.[1]

The following table shows the quantities of ore that have been shipped from the Mayari mines to the United States:—[2]

Year.	Tons.
1910	307,700
1911	387,791
1912	446,176
1913	491,713
1914	228,949
1915	300,896
	2,163,225

The ore shipped in 1915 carried 36.32 per cent. (natural) of iron and 56.30 per cent. (nodulized).

The characters of the iron and steel produced from Mayari ores are described on other pages of this report.

CHINA

The following note on the occurrence and uses of nickel in China is by T. T. Read.[3]

Nickel is of much technical interest because of the ingenious way the Chinese have of smelting mixtures of nickeliferous copper-ores with tin, lead, and zinc-ores, forming the alloy "pai-t'ung," or "pahfong," as it is called in southern China. This is a kind of German silver, which is extensively used in the manufacture of candlesticks and other household objects. Nickel is never produced separately, and the entire supply is apparently drawn from southwestern China, where in Yunnan (at 100°20′ E. 26°50′ N.) and in Ssu-chuan (100°20′ E. 26°45′ N.) Duclos has noted the occurrence of nickeliferous copper-ores.[4]

EGYPT

A small quantity of nickel ore, similar to that of New Caledonia, has been mined in Egypt from a deposit associated with peridotite on St. John's Island, Red Sea. On the mainland, there is also peridotite, and some large areas of serpentine, which may prove to be nickel-bearing.

The following description of the St. John's Island occurrence has been furnished by Max Ismalun, through R. H. Greaves, chief of the Department of Mines, Egypt.

There is a hill 1,000 feet high, composed of peridotite, which has pierced through the Tertiary beds of the island. These beds are represented by coloured limestone and carbonaceous sandstone and gypsum, and sometimes by schists or gneisses.

The peridotitic rock has various aspects as far as colour, grain and hardness are concerned, and presents a great quantity of fractures which probably took place during the cooling stage of the peridotitic magma.

These fractures are generally filled up with serpentine. . . .

The nickel ore, similar to garnierite, also occurs in veins more or less, vertical, whose fractures have probably the same origin; but are generally of much greater size. One of these veins has been proved to have a length of 150 feet, a depth of 120, and a thickness varying from 2 to 5 feet.

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[1] The Mineral Industry, 1913.

[2] Mineral Resources of the United States, 1915, Part I, p. 317.

[3] Am. Inst. M. E., Vol. XLIII, 1912, p. 45.

[4] Duclos: La Mission Lyonnaise d'exploration commerciale en Chine, 1895-7, pp. 283 to 318 (Lyons, 1898).

The filling itself is a mixture of garnierite and iron oxides, and has a banded aspect; that is to say, there is a longitudinal band of garnierite in the centre, on both sides of which occur two bands of iron oxides, then again two bands of garnierite, and so on.

When working the vein, which is very friable, it is hardly possible to separate the two kinds of ore. This, moreover, would not be advisable, as the iron oxides contain 2 to 4 per cent. of nickel.

The composition of the garnierite ore is as follows:—

	Per Cent.
Ni	9.48
SiO_2	32.26
Al	4.89
Cu	0.40
Fe	15.42
Mn	0.19
Cr	0.08
CaO	0.26
MgO	18.51
S	0.12
O	9.34
H_2O	9.01
Total	99.96

The mixture of garnierite and iron oxides averages 6.5 to 7 per cent. Ni. This ore would be first class did it not contain about 0.5 per cent. copper impurities, that are an obstacle to any smelting process. Electrical separation has been tried with success and seems to be advisable for this kind of ore.

It has been noticed that the proportion of iron oxides increases in depth and that naturally the garnierite diminishes.

Development work is not sufficiently extensive to enable us to figure the quantity of high-grade ore available. A few thousand tons are in sight at the present moment. Besides the vein filling, I have found some impregnated superficial patches of ground containing from 1 to 2.75 per cent. Ni. Should these be workable on the spot, the ore tonnage would be greatly increased.

FRANCE

Rich silver ores, with cobalt and nickel minerals, discovered in 1767, were worked at Chalanches, Dauphiné, France. The ores occurred in a network of narrow veins in crystalline schists. That the presence of nickel and cobalt was not recognized in the earlier period of working is seen from the following quotation:—

It is not a little remarkable that although the silver is always associated in the lodes with rich nickel and cobalt ores, often with bunches of stibnite, and more rarely and erratically with gold, the government engineers took no notice of any metal other than silver. None of the valuable metals mentioned figure in the old-accounts. The speiss containing nickel and cobalt was rejected with the slags, and went to fill the swamps and to form the road-beds, which, in later times, were furrowed and turned over to recover their valuable contents. . . .

The possibility of utilizing three metals instead of one seems to have dawned upon the engineers quite as a discovery; and this fact stimulated the repeated spasmodic attempts to rehabilitate the old mine. The arsenides of nickel and cobalt were sold in England and Germany. More recently, a German chemist was employed at Allemont in an experiment to manufacture cobalt pigments for the arts. He was not successful, and the attempt was abandoned.[1]

GERMANY AND AUSTRIA

Although deposits from which nickel-bearing ores have been mined occur in a considerable number of localities in Germany and Austria, in normal times the production of the metal from domestic ores is comparatively small. Owing to conditions that have existed during the war, it is likely that the production from domestic ores has been increased. Certain deposits that have been lying dormant for years would probably be reopened.

[1] T. A Rickard, Trans. Am. Inst. M. E., Vol. XXIV.

As shown on preceding pages, for many years part of the nickel ore produced in New Caledonia has been refined in Germany. But prior to the war the greater part of the nickel used in the two countries was imported in the refined state.

Several varieties of nickel ores have been mined in these countries. They include arsenides, sulphides, and silicates, corresponding to those of Cobalt, Sudbury and New Caledonia, respectively. The following deposits, some of which are of little more than historical interest, may be mentioned:—

(1) Arsenical ores carrying cobalt, nickel and other metals, such as those of Dobschau, Annaberg, Schneeberg, Joachimsthal and Dillenburg.

(2) Pyrrhotite ores of Sohland,[1] discovered in 1900, Schweiderich, and Horbach.

(3) Silicate ores:—"In recent years nickel has been extensively mined at Frankenstein in Prussian Silesia . . . At the present time the nickel deposits have been mined to a depth of 183 ft. . . . In 1901, 9,500 tons of ore were extracted and 114.3 tons of nickel were produced. There was a considerable increase of production in 1902."[2]

GREAT BRITAIN

That nickel ores have been produced in Great Britain, one of the largest refiners of foreign ores, is seen from the following notes:—

Pentlandite, a sulphide of iron and nickel, was some years since worked at Glen Essochossan, two miles from Inveraray, as well as at Craignure, in the vicinity of Loch Fyne, eight miles distant from the same town. About 300 tons of ore averaging 14 per cent. of nickel are stated to have been sold from these mines In a sample of the ore from the Craignure mine Mr. F. Claudet found, in addition to the usual percentage of nickel, a considerable amount of tin oxide.[3]

In Great Britain nickel is found associated with iron at Voel Hiradig, Cwm, in Flintshire. Since 1870, 675 tons 14 cwt. of nickel iron ore have been raised on this mountain, of the value of £3,691, or about £5 10s. per ton. The average proportion of nickel was 2.3.[4]

GREECE

In Greece both nickeliferous iron ore, similar to that of Cuba, and garnierite, resembling the New Caledonia ore, have been produced.

The following notes concerning the Grecian deposits are taken from a paper by H. K. Scott,[5] little having been published by other writers descriptive of these occurrences.

With the exception of some mineral used by Mr. Arthur W. Richards for the production of a high-class steel in 1907, the Greek chromiferous iron ore imported into this country has been mixed with other ores for the production of ordinary steel, which has involved the elimination of the chromium at some trouble and expense. . . . Chromiferous iron ores occur in the western part of Greece in the States of Lokris and Boitio, and on the islands of Eubœa, Skyros, and others of the Grecian Archipelago. The most important deposits are situated in the district bounded by the bed of the drained Lake Copias and the west coast of the Talanta Channel. The country is mountainous, rising in places to 4,000 feet above sea level, and the climate is healthy, except on the bed of the extinct lake, where the marshy ground fosters malaria.

[1] C. W. Dickson, Jr. Canadian Mining Inst., 1906, p. 253.

[2] Beck, The Nature of Ore Deposits, 1903, Weed's translation, p. 349.

[3] A Treatise on Ore Deposits, J. A. Phillips and Henry Louis, 2nd ed, p. 321.

[4] Metalliferous Metals and Mining, D. C. Davies, 1888, p. 287.

[5] Chromiferous Iron Ores of Greece and Their Utilization, Jr. Iron and Steel Inst., No. 1, for 1913, pp. 447-467.

The deposits are all within a few miles of the coast, which, being much indented, furnishes excellent loading ports.

Chromiferous iron ore was first discovered in Greece by an Italian named Novara, who had worked at the Laurium lead-zinc mine and was prospecting in the Larmes district in 1901, on behalf of the former Minister of Marine, Boudouris. Subsequently other ore bodies were found in the vicinity and on the islands already mentioned. . . . Shipments of the mineral to the end of 1912 have been as under:—

Property.	Tons.
Lokris	430,000
Thebes	600,000
Tsouka	400,000
Lutzi	200,000
Skyros	300,000

In 1909 a discovery was made in the Thebes and Lokris deposits of garnierite (the hydrated silicate of magnesium and nickel) containing 4 to 5½ per cent. of nickel in the dry ore, and of this 24,000 tons has been exported. . . .

The principal formations represented in Greece are the Archæan, Cretaceous, and Tertiary systems, with volcanic rocks in abundance, of which serpentine, altered from peridotite, covers a large part of the Grecian mainland, as well as the island of Eubœa and others, and even extends to Asia Minor. Over the whole of this serpentinous area chrome and chromiferous iron ores are reported to occur, although they are often not sufficiently pure to have any economic value.

In the Lokris and Boitio districts, segregations of irregular character, as well as ore bodies of lenticular form, are found, either as fissures in the limestone of Cretaceous age, as at the Thebes and Lokris properties, or as contact deposits between the serpentine and limestone, as at Tsouka, Karditza, Lutzi, and probably Pavlorado. Whilst the deposits have as a rule their longer axes parallel with the lines of cleavage or contact of the enclosing rocks, those in the fissures of the limestone are more irregular in shape, presumably by reason of the substitution and erosion of the "country" rock being more general, and are distinguishable from the contact deposits, which assume a banded character.

The ore consists of hard grains or shot-like particles and nodules of irregular shape, up to half an inch in diameter, of brown hematite which has a sub-metallic fracture, associated with a variable quantity of a binder or matrix of a more hydrated, amorphous, and softer ore which often exhibits "slicken-sides."

In the Tsouka and Karditza properties the mineral is quite compact and bears transport without making small, but the greater part of the ore from the Thebes and Lokris deposits, as well as that of Lutzi, disintegrates on handling, and assumes a physical condition which is prejudicial to its use in the blast-furnace.

The composition of the ore, in the dry, of the different deposits varies within the following limits:—

	Per Cent.
Iron	46 to 52
Alumina	6 " 14
Silica	5 " 11
Chromium	2 " 3
Nickel and cobalt	0.10 " 1.2
Phosphorus	Trace " 0.03
Sulphur	0.02 " 0.05
Titanium	Trace " 0.30

The garnierite is found only in the Lokris and Thebes deposits, irregularly distributed in the serpentine on the foot wall of the chromiferous iron ore. It exists in small stringers or nests, and the mineral is invariably in a finely divided state.

Regarding the genesis of these deposits, it may be referred to a peridotite, containing appreciable quantities of chromium, nickel, and cobalt, which has been intruded into the Cretaceous limestone. . . .

By reason of the irregular occurrence of the chromiferous iron ore and the garnierite, it is not possible to estimate the quantity of either mineral in the Greek deposits likely to be available for extraction at a profit. The chromiferous iron ore deposits are, however, so large and well distributed that they will no doubt yield a large quantity of mineral for many years, although exploratory work has proved that in several of them, notably those of Lokris and Thebes, the mineral proves to be somewhat poorer in depth, the iron contents being reduced to 45 per cent. in the dry ore. . . . The Lokris and Thebes ore bodies occur on several spurs, separated by deep ravines, of the Scropo Neri mountains, seven miles to the southwest of the port of Larmes. The highest point of the outcrop is 1,200 feet above tide and 600 feet above the bed of the extinct Lake Copias. The deposits have a general north-northeast direction, and a dip varying from the vertical to 30° to the west-northwest.

The mineral is intercalated between walls of white limestone in lenticular-shaped bodies, which in places swell out into what are termed "pockets," in which the ore is much mixed with boulders of the "country." Between the mineral and the enclosing rock a ferruginous schist or altered serpentine is found, and the limestone of the hanging wall has a yellowish tinge over a limited thickness. . . .

At the time of the author's visit there was no appreciable difference in either physical condition or composition between the quarried ore near the surface, and that mined 250 feet below on the Lokris property. A number of quarry samples gave 47.5 per cent. of iron, whilst several samples from the underground workings contained 47.9 per cent. of iron in the dry. Further underground work at a lower level has, however, indicated a gradual decrease in the percentage of iron.

The average composition of the mineral in the dry ore from the Thebes and Lokris properties is as follows:—

	Per Cent.
Iron	46.00
Alumina	14.00
Silica	8.00
Chromium	2.50
Nickel and cobalt	0.60
Phosphorus	0.02
Sulphur	0.03

. . . . .

The Tsouka property is nine miles northwest of the port of Larmes. The mineral outcrop contours two conical hills, covered by a residual clay, over a length of one and a half miles, at a height of 800 feet above sea level. The deposit lies on the serpentine with limestone as the hanging wall, and dips 5° to the northwest.

The ore-body averages 10 feet in thickness, and consists of compact hæmatite either of an amorphous character with sporadic pellets which have a metallic fracture, or as a conglomerated mass of a pisolitic character. The mineral in the upper part of the deposit is somewhat softer than the rest, but even so, the physical condition of the mineral is excellent for the blast-furnace. Its average composition in the dry is as follows:—

	Per Cent.
Iron	52.00
Alumina	7.00
Silica	7.00
Chromium	2.00
Nickel and cobalt	0.70
Phosphorus	0.01
Sulphur	0.04

The Karditza deposit is five miles southwest of the Thebes property, and the ore outcrops on the summit of a hill over a length of upwards of half a mile with a southeast strike, and dips to the southwest with an angle of 30°.

The mineral lies between the limestone and serpentine, and, at the time of the author's visit, had been approached by a cross-cut 200 feet in length from an adjoining ravine through the altered eruptive. The contact with the limestone is somewhat sharp, but on the "foot" the deterioration in the quality of the ore is gradual as the serpentine is entered.

The ore-body had been drifted upon over a length of 300 feet, and was found to average 10 feet in thickness. . . .

The total cost (including State charges) of placing mineral f.o.b. loading port is about 5s. per ton, and the selling price is 5s. to 5s. 3d. per ton, with 10d. for loading, or say 6s. per ton.

The freight rate of tramp steamers to Western European ports was recently as high as 10s. per ton, but is now 7s. per ton.

From the quotations given it will be seen that certain of the nickeliferous iron deposits of Greece occur under somewhat different conditions from those of Cuba and the garnierite ores of New Caledonia. In the case of both these countries the ores form a mantle on the surface of the serpentine from which they have been derived. The Grecian deposits, in the descriptions quoted, appear to have been formed from the weathering of dikes, which occupy fissures in Cretaceous limestone, or from the weathering of serpentine over which lies a wall of limestone. Moreover, the Grecian ores are mined to a much greater depth than those of Cuba and New Caledonia.

The following note concerning the Grecian garnierite ore is of interest:—

One of the most interesting nickel deposits in Europe, on the Grecian island of Lokris, east of Athens, is at present attracting attention, and may prove to be of value in the future. This was not visited by the writer owing to lack of time; and there appears to be no description of it in print. Through the kindness of Dr. Mohr, of London, and Mr. V. Hybinette, of Kristianssands, Norway, brief accounts of the mine were given me, as well as specimens of the ore. The mine was opened for hematite and has been worked as an iron mine; but below the iron ore a somewhat rich ore of nickel is found, dull brownish and earthy in appearance, but with some bands or spots of apple green material suggesting genthite or garnierite.

A complete analysis made for the Kristianssands nickel refinery shows the following composition:

SiO_2	37.00	
Al_2O_3	9.81	
Fe_2O_3	28.37	(Fe=19.86 per cent.)
MnO	2.85	(Mn= 1.92 per cent.)
CaO	0.39	
MgO	1.91	
S	0.06	
As	0.15	
CuO	0.07	(Cu = 0 06 per cent.)
NiO	9.17	(Ni = 7.22 per cent.)
Co	Traces	
P_2O_5	0.09	
Loss on heating	8.50	
Cr_2O_3	1.37	
	99.74	

From its appearance the ore suggests the weathering of a basic eruptive rock, such as peridotite or serpentine, with the accumulation of the nickel toward the bottom of the products of weathering, and so may be compared with the New Caledonian deposits, though with much less of the green nickel magnesia silicate, garnierite.

This ore deposit has been examined by the Mond Company and the Norwegian Company, and the latter have made use of a shipload of the ore, some of which is still to be seen at the Evje smelter. A portion of the nickel produced at the Kristianssands refinery is therefore not from Norwegian, but from Grecian ore.

So far as known at present none of the European nickel deposits are of sufficient magnitude or of sufficiently high grade to be serious rivals of the Canadian and New Caledonian mines; and much the largest part of the nickel refined in Europe comes from these two regions.[1]

INDIA

The following notes summarize the information available concerning the modes of occurrence, consumption and uses of nickel in British India:—

Ores of nickel (nickeliferous pyrrhotite) have been found amongst the copper-ores of Khetri and other places in Rajputana. Nickel has also been detected in small quantities in chalcopyrite and pyrrhotite found associated with the gold-quartz reefs of Kolar, and in pyrite said to be from the Henzada district of Burma. Complex sulphide ores, consisting of pyrrhotite, pyrite, chalcopyrite, and molybdenite, have been received from the Tobala taluk in South Travancore. Both nickel and cobalt are present in quantities beyond mere traces, but nothing is yet known as to the extent of the deposits, nor have any proper average samples been assayed. A surface sample of ore showed 1.20 per cent. of copper, 0.64 per cent. of nickel, and 0.08 per cent. of cobalt, with 12 grains per ton of gold and 2 dwts. 12 grs. per ton of silver. Further investigations may show that the deposits are richer than is indicated by this analysis.

There is a considerable consumption of nickel in India in the form of German-silver, the annual imports of which during the five years 1909 to 1913 have averaged 1,103 tons, worth £115,388. . . . Further, on the 1st August, 1907, the issue to the public was commenced of the new 1-anna nickel coinage, consisting of an alloy of 25 parts of nickel with 75 of copper, leading to a further consumption of nickel, statistics for which are not available.

The imports of nickel received at the Bombay Mint during the period 1909-13 have totalled 175.3 tons (4,767 maunds 2,734 tolas) valued at £30,671.[2]

[1] A. P. Coleman, The Nickel Industry, Mines Branch, Ottawa, No. 170, pp. 117-118.
[2] Records of the Geological Survey of India, Vol. XLVI, 1915, pp 281-2.

ITALY

Nickel deposits of Varallo, Piedmont, Italy, although small, are of interest, since, in mineralogical composition and in their association with basic rocks, they resemble those of Sudbury and Norway. Like many other small deposits, they were worked in the period preceding the discovery of the New Caledonia ores and a little later. In 1876 two mines had a total production of about 2,800 tons of ore, containing 1.20 to 1.44 per cent. of nickel, 0.36 to 1.00 of cobalt, 0.50 to 0.72 of copper, and 28.00 of sulphur.[1]

MADAGASCAR

During the last few years attention has been directed to an occurrence of nickel in Madagascar, where the metal is found under conditions similar to those of that other French colony, New Caledonia. The garnierite ore in Madagascar, compared with the occurrences in New Caledonia, covers only a small surface.

In a letter dated August 19, 1916, from A. E. Roberts, President, Syndicat Minier de Madagascar, the Commissioners received permission to publish the following description by him of the deposit, said to be the only proved Madagascar deposit:

> The deposit is situated immediately to the south of the village of Valzoro, District of Ambohimasoa, Province of Fianarantsoa, Madagascar. The port of Mananjary is situated 145 miles to the southeast of the property.
>
> The total area of the concession is 1.5 x 1 kilometres, or 370.5 acres. Work so far has proved the existence of nickel ore on 82 acres; further exploration will probably slightly increase this area.
>
> The nickel occurs as garnierite. By the work carried out by our engineer, the existence of nickel ore has been proved to extend over an area of 82 acres, which forms a hill, situated in the centre of the concession. This hill has a height of 500 feet above the lowest part of the deposit, *viz.*, the bed of the stream in the southeast corner. The deposit consists of a laccolith, or mass of ultra-basic rock, which probably at the time of its upheaval did not quite reach the surface, subsequent denudation having laid it bare in places. Through shrinkage in cooling, and by the pressure of the overlying gneiss, the basic rock has been split into a network of seams and cracks. Along these irregular lines of breakage the original rock has been altered to serpentine.
>
> The nickel is found in these cracks in thicknesses varying from a film to over an inch, and the nickel has also permeated into the soft serpentine. The depth to which the alteration extends has not been proved, but shafts have been sunk to a depth of 60 feet without passing beyond the altered zone. . . . .

Judging from what is known of deposits of this kind in New Caledonia, Cuba, and elsewhere, a thickness of 60 feet or more of this ore would not contain merchantable material throughout. As decomposition of the rock proceeds from the surface downward, nickel and certain other elements tend to migrate and are carried downward by water. Hence it would be expected that the upper part of the Madagascar deposit would not contain nickel in economic quantities, but that the lower part would contain a greater concentration of the metal.

From another source it is learned that ". . . . in one of the groups of nickel mines. . . . there are 125,000 tons of 5.5 per cent. ore, with a further probable 250,000 tons of 4 per cent."

There are two ports from which the ore or its products might be shipped, Tamatave, about 360, and Mananjary, 120 miles from the property. The latter is

[1] Badoureau, Métallurgie du Nickel, Paris, 1877.

an undeveloped port, and seems likely to remain so, while the construction of a continuation of the railway from the former to the vicinity of the deposit may be looked for in time.

Water power capable of producing 3,000 or 4,000 horsepower is said to be available within about 35 miles of the deposit. There is a supply of sulphur on the island, together with charcoal and other materials.

It is said that a new process of refining has been tried on these ores with promise of success.

MEXICO AND SOUTH AMERICA

Nickel has been refined in Europe from South American ores, apparently produced as by-products in the mining of silver and other ores. Both cobalt and nickel occur in a number of localities in Mexico and South America, but no important deposits are known.

PHILIPPINE ISLANDS

In the island of Mindanao are found deposits of iron ore of similar character to those of Cuba and Borneo, already described. While the only detailed analysis available, quoted below, shows chromium, it gives nickel as being absent. It is scarcely to be expected, however, that on further investigation nickel will be found to be absent in all parts of these large deposits. The Philippines can be said to be neighbouring islands of Borneo and Seboekoe. The situation of Mindanao is shown on the map, page 234.

The following notes on the Mindanao deposits are taken from a paper by W. E. Pratt[1] :

On the eastern coast of Surigao Province in Mindanao there is an area of about 40 square miles, bordering the sea for a distance of 10 miles, which is conspicuously barren of vegetation and is covered with a bright red soil. This condition is the more notable in that the surrounding country is heavily forested, and the singular barren appearance of this one section of the coast line has been a subject of interest for years to those who knew of it. But the region is sparsely inhabited, and but few boats pass along that coast; consequently it was not until the year 1914, when H. F. Cameron, an engineer who is familiar with the iron ores of the Nipe Bay region in Cuba, made an inspection trip through Surigao that the "Red Hills" . . . were found to be covered with laterite rich enough in iron to constitute an ore.

The laterite mantles a dissected plateau ranging up to 1,500 ft. in elevation and terminating along the coast in sea cliffs and steep slopes. This part of Mindanao receives a rainfall that averages about 10 ft. annually. . . .

While there are no regular harbours near the ore deposit, Dahikan Bay, at its southern extremity, is almost landlocked, and is perfectly protected at all seasons. . . .

The ore deposit and the ore itself are strikingly similar to the lateritic iron ores of the Mayari district in Cuba. . . .

The Philippine laterite, or iron ore, is a surface blanket of residual clay varying in thickness up to 60 ft. and resting upon the parent rock from which it has been derived by tropical weathering processes. . . . .

The parent rock, wherever exposed within the limits of the ore deposit, is essentially serpentine.

In composition the Surigao iron ore appears to be slightly inferior to the ores of the same character in Cuba. . . . The results of the sampling tests indicate that the Surigao ore is remarkably uniform in composition throughout the deposit. . . .

[1] Am. Inst. M. E., Vol. LIII, W. E. Pratt, The Iron Ores of the Philippine Islands, pp. 101, 102, 103, 104, 105.

The only detailed analysis of the Surigao ore was performed upon a sample taken from the surface by Mr. Cameron. This analysis follows:

	Per Cent.
Hygroscopic water	13.50
Combined water	6.60
Silica	1.04
Alumina	10.56
Ferric oxide	66.80
Ferrous oxide	0.36
Chromium oxide	1.15
Nickel oxide	nil
Sulphur	trace
Phosphorus	trace
Total	100.01
Metallic iron, dried ore	54.29
Metallic iron, ore deprived of combined water	58.20

In its lack of nickel, as represented by the single analysis, the Surigao ore is different in an important respect from the Cuban ore. . . .

In attempting to ascertain what quantity of ore is present in the Surigao deposit and what percentage of iron is contained in the average ore, hand drills were employed to determine the thickness of the ore mantle at different places and to secure representative samples of the ore from different depths. . . . From these figures and the weight of a unit volume of the ore in place it can be calculated that the total economically important metric tonnage is 430,000,000, of which about 375,000,000 tons is contained in that part of the ore mantle which is 10 ft. or more in thickness.

RUSSIA

At Redwinsk (or Revda), in the Urals, are nickel deposits of the garnierite type, resulting from the weathering of serpentine, which is intercalated between schists and crystalline limestone. Attempts were made to mine these deposits as early as 1866, and there has been a small production at various times. Judging from the following, more serious attempts at utilizing the ore have recently been made:—

Russian nickel deposits in the Urals, which have not heretofore been worked on account of the low grade of the ore, are now being exploited. The ore mined is being treated at the Redwinsk smelting works, which are reported to be turning out at the rate of 600 tons yearly of nickel matte.[1]

SOUTH AFRICA

The occurrence of nickel-copper ores in association with a sheet of basic rocks in the Insizwa range has caused various writers to compare these South African deposits with those of Sudbury. But there is only a distant geological similarity between the two. Moreover, no workable deposits have yet been found in the Insizwa range, although attention has been directed to the occurrence for a number of years. Should large masses of picrite with disseminated ores be discovered, the probability of which has been suggested, such deposits would scarcely be serious competitors of the large massive ore deposits at Sudbury.

A very interesting and complete description of the modes of occurrence of these nickel-copper ores has recently been published by W. H. Goodchild.[2] This paper includes observations of earlier workers, besides containing much information gathered by Goodchild himself.

[1] Eng. & Min. Journal, Nov. 6, 1915, p. 759. See also Vol. XLVIII, pp. 118-124, A. I. M. E.

[2] Economic Geology of the Insizwa Range, Inst. Min. & Met., Bull. No. 147, Dec. 14, 1916, with discussion, Bull. No. 148.

The structural relations of the gabbro sheet, consisting of olivine gabbro, picrite and other varieties, are described in the following extracts from Goodchild's paper:

Overlying these hornfelses is the great gabbro mass which gives rise to a bold, steep and frequently precipitous escarpment with peaks situated a little way behind the escarpment, rising to heights over 3,000 ft. above the level of the neighbouring valley and more than 6,000 ft. above sea level. A rudely columnar structure is not infrequently shown in the cliff face. On the mountain top and at varying distances from the face of the escarpment, the upper surface of the intrusive dips inward at low angles under another series of hornfelses resembling in a general way those at the base. These pass gradually into a series of sedimentaries also similar to those at the base and, like them, they are also lying practically horizontal. . . .

The thickness of the gabbro sheet varies. It probably averages some 2,000 ft. and exceeds 3,000 ft. in its thickest parts. The dip of the sheet is inwards towards the centre of the oval, and the dip of the basal contact round the periphery of the mountain, though varying considerably from point to point, probably averages about 30°. The shape of the gabbroid mass is therefore roughly that of a thick shallow basin. It thus stands in a cross-cutting relation to the bedding planes of the encasing sedimentary rocks and is not truly laccolithic in its mode of occurrence.

According to Goodchild, the ore deposits may be classified into four distinct types:

(1) Mineralized norite or picrite containing disseminated sulphides of copper, nickel and iron.

(2) Small fissures filled almost entirely with sulphides of copper, nickel and iron.

(3) Vein-like sheets of acid rock containing similar sulphides disseminated and in masses.

(4) Dolerite dykes, cutting the main sheets and sedimentaries, containing disseminations and thin veinlets of sulphides and occasional arsenides of the same series of metals.

All four types have this feature in common, namely, that they carry sulphides only in the near neighbourhood of the lower hornfels-gabbro contact. Types (3) and (4), however, may contain ore minerals at considerably greater distances from the contact than (1) and (2).

The mineralized picrite is probably the most important kind of deposit as yet discovered at Insizwa, since it appears to possess greater economic possibilities than the others. . . . . . . It would scarcely be surprising, therefore, if prospecting of the lower margin of the intrusive at greater distances from the face of the escarpment than has hitherto been attempted led to the disclosure of large bodies of mineralized picrite of profitable grade, despite the fact that nowhere along the range is there any outcrop of this mineralized rock of sufficient grade to enable it to be exploited at a profit. . . .

The solid sulphide veins are of small dimensions and irregular in all their characteristics. They occur in the near neighbourhood of the hornfels-gabbro contact, commonly passing a short distance up into the sheet and down into the hornfels. Individual fissures have been traced for a horizontal length of 100 ft. or so, and, while they occasionally attain a width of 2 ft., 6 ins. is probably a liberal estimate of their average thickness. They ramify and have no well-defined strike or dip, though there seems to be a tendency for them to strike with a rough parallelism to the contact. The fissures are filled almost entirely with sulphides of copper, nickel and iron, but the relative proportions of the minerals are subject to the widest variations from point to point. The copper contents may vary from 1.5 per cent. to 20 per cent, nickel from 1 5 per cent. to 10 per cent., while the average is probably about 4 per cent. of each of these metals. Platinum is frequently present but is erratically distributed. The average, as far as can be judged, is probably between 2 and 3 dwt. per ton, a by no means inconsiderable amount, while occasional samples containing several ounces to the ton have been obtained. Gold and silver are also present in small amounts.

The hornfelses in the near neighbourhood of these veins also occasionally contain small pellets of sulphides as well as small amounts of fine disseminated sulphide

These veins seem to be akin to gash veins and they are the "will-o'-the-wisp" formations upon which the greater part of the mining activity along the range has been concentrated hitherto, with disappointing results. They appear to be distributed over a wide area, for the most random kind of prospecting at many points separated by wide intervals has shown their presence, even where there are no definite surface indications of their existence. It seems to have been quite the exception for an adit to be driven to the contact without striking either mineralized rock or one or more of these stringers. The exceptions generally occur where the overlying gabbroid rock is of a more acid character than picrite. . . .

The order of separation of the sulphides in the picrite, as determined by du Toit, is (1) chalcopyrite, (2) pentlandite, (3) pyrrhotite, and, as he points out, this is exactly the reverse of that obtained by Campbell and Knight in the copper-nickel deposits of Sudbury, Norway and elsewhere.

"He [Goodchild] concluded by saying that there was nothing more than a distant geological similarity between the Insizwa and Sudbury occurrences, although Insizwa had on several occasions been dubbed 'The Sudbury of South Africa.'"[1]

Two trial shipments of some five tons each, apparently from the "solid sulphide veins," sent to Johnson, Matthey & Co., on analysis gave the following results:—

	1	2
Copper	3.40 per cent.	3.50 per cent.
Nickel and cobalt	4.90 per cent.	5.25 per cent.
Gold	6 grains per ton.	6 grains per ton.
Platinum	2 dwt. 12 grains.	12 grains.
Silver	10 dwt.	12 dwt.

The mineralized area of the Insizwa range is situated close to the boundary between East Griqualand and Pondoland, some sixty miles from the east coast of the Continent, in the well-watered region drained by the upper tributaries of the St. John's river. The Tritsa falls, said to be the second largest falls in South Africa, are distant about forty miles from the centre of the range; at the mouth of the main river is the port of Fort St. John's.

A little work appears to have been done on the copper veins in this range about 1865, but it was not until over forty years later that the sulphides, supposed to contain copper and iron only, were found to contain nickel also. Shortly afterwards the presence of platinum in the ores in variable but appreciable quantities was discovered.

In connection with the occurrence of nickel in South Africa, it may be added that considerable cobalt is contained in crude copper produced in the Belgian Congo, which, prior to the war, was refined in Germany. It has been estimated that probably 242 tons of metallic cobalt were derived from this source in 1913.[2]

SPAIN

A small quantity of nickel ore, of the garnierite type, was mined in the 'seventies in Malaga, Spain. Upper portions of the serpentine here contain secondary ores, garnierite and pimelite, and at greater depth the nickel arsenide, niccolite, is found.[3]

TASMANIA

Nickeliferous pyrrhotite occurs in deposits of small size in Tasmania, near the town of Zeehan. A few thousand tons of ore have been mined, and, although diamond drilling has been done on the deposits, but little ore has been proved to remain. While the ore is rich, the deposits are of little importance as competitors.

[1] Inst. M. & M., Bull. No. 148, p. 3.
[2] Min. Res. U. S. G. S., 1913, Part I, p. 339, and Min. Sci. Press, Feb. 21, 1914, p. 322.
[3] F. Gilman, Notes on the Ore Deposits of the Malaga Serpentines, Inst. Min. and Met., 1896.

Immediately prior to the war, January to July, 1914, about 3,000 tons of ore were mined and shipped to Germany. This ore averaged 10.368 per cent. in nickel and 5.291 in copper. The percentage of iron was about 42 and that of sulphur 38. It may be added that a little garnierite occurs near Trial Bay.

The following quotations, from two papers, one published in 1902 and the other in 1915, give the character of the deposits and associated rocks:—

1. There are two deposits of this class known in the North Dundas district, and, though there is reason to believe that neither of them is of commercial value, it is important that the facts of their occurrence should be recorded, as deposits of the same class which are of sufficient dimensions to become of economic value may be found in other parts of the coast.

The most important of the two deposits in the North Dundas district is situated on section 3510-93m, near where the Emu Bay Railway crosses the North-East Dundas Tramway. The deposit was found in the bed of a small creek which flows through the section. The creek had completely filled up the old workings and I could not examine them, but Mr. G. Beardsley, metallurgist to the Mt. Lyell M. and R. Company, who was interested in the mine at the time the work was done, has kindly furnished me with the following information:— The deposit occurred at the junction of the slate and the decomposed gabbro. On first appearance it gave promise of being a big lode, but afterwards proved to be merely a rock-cavity filled with nickeliferous pyrrhotite. This was connected with a small leader a few inches thick and 12 or 15 feet in length. The water was very heavy, and the leader was not followed down for more than 20 feet. Several parcels of ore were sold, carrying from 8 to 12 per cent. of nickel, 3 to 5 per cent. of copper, an ounce or two of silver, and a trace of gold. The ore was composed principally of nickeliferous pyrrhotite, containing in places small crystals of millerite. This occurrence is evidently of the same type as the nickeliferous pyrrhotite deposits of Sudbury, in Canada, though on an extremely small scale. These deposits are invariably found at or close to the contact of gabbro with the surrounding rocks, and occasionally form short veins in the latter. . . . The dimensions of the gabbro intrusions at North Dundas are very small in comparison with the enormous masses which occur in Canada and Norway, and this may account to some extent for the small dimensions of the ore deposits. North of the Pieman River, however, very much larger masses of gabbro are known, and it would be well worth while for prospectors in that district to be on the look-out for large deposits of pyrrhotite at the contact of the gabbro and the sedimentary rocks. . . .

The other deposit which I have referred to is situated on the old King Curtain Mine, about three-quarters of a mile north of Ringville. The formation was cut in an old tunnel which was put in from the side of the track between Ringville and the Colebrook mine. I have only examined the ore at the mouth of the tunnel. It consists of veins and bunches of iron pyrites in quartzite, with small needles of millerite through it. The quartzite also contains small needles of millerite in the joints Just beyond the tunnel the track passes through a small patch of serpentinised gabbro, so that it is evident that this deposit is also at or close to the contact of this rock. I am not at all sure that this deposit belongs to the same type as the last, but I think it is probable. The millerite in the joints of the quartzite is evidently of secondary origin, and indeed the whole deposit may have been altered considerably by the action of underground waters since it was formed as a segregation from the gabbro.[1]

2. The two principal known occurrences of the metal are in the west of the island, one of which is in the Dundas mining district near Zeehan, and the other on the west coast at Trial bay, 14 miles away. During the past three or four years considerable development work has been done on the Dundas deposit, where four separate ore-shoots of high-grade copper-nickel ore have been found on a line of contact between serpentine and slate rocks extending for about a mile north and south. Two of the ore-shoots have been recently worked by private companies, which acquired adjoining properties. . . .

The deposits occur in the slate near its contact with the serpentine, as shown on the cross-section through one of the deposits developed. It will be seen that the irregular lenticular masses of ore that are farthest from the serpentine have pinched-out at shallow depths, while the ore-shoot nearest the contact with the serpentine continues downward from the surface so far as exposed, and has more the aspect of a contact-fissure deposit, which it may prove to be on further development.

The ore-shoots are principally composed of sulphides of iron, nickel, and copper, or nickeliferous pyrrhotite, and contain from 8 to 12 per cent. Ni and 4 to 6 per cent. Cu; lower-grade ore also occurs at a depth of 70 ft. in a portion of the lode nearest the

[1] Report by G. A. Waller to Secretary for Mines, Hobart, dated Zeehan, April 30, 1902, pp. 64-66.

serpentine, the face of the drift on it showing at one place 6½ ft. of ore, 4 ft. of which assayed 8.26 per cent. Ni and 4.2 per cent. Cu, the remaining 2½ ft. assaying 1.17 per cent. Ni and 1.80 per cent. Cu. Secondary enrichment is evidenced by the richer ore being found nearest the surface and by the ore becoming harder and more silicious with depth. The following assay of a 100-ton lot shows approximately the average contents of such ore as has been mined and shipped up to date: Ni 9.61 per cent., Cu 4.7 per cent., Fe 32.8 per cent., S 32.66 per cent., SiO_2 5.24 per cent. Some silver and platinum are present, as indicated by an assay for precious metals made by Daniel C. Griffith & Co., of London, who reported Ag 2.2 oz. per ton, Au trace, Pt 0.06 oz. per ton.

The association of nickel with serpentine is well known, and it has been proved to be one of the chief sources of the metal, though the ore deposits derived from it may be either of a secondary nature, resulting from erosion of the parent rock, or be primary deposits of magmatic origin. In the present instance the serpentine near the surface contains no traces of disseminated ore, as far as is known, yet it is quite admissible as the origin of the sulphide ore-shoots under notice, which are recognizable as contact-fissure deposits formed through the agency of ascending thermal solutions, subsequently enriched by erosion and descending surface water. It does not, however, follow that these ore-shoots, even if originating from a deep-seated source, will prove of great persistence in depth; other factors, known to students of ore deposition, require due consideration, and in the present case point to an early impoverishment with depth.

The Dundas deposits, although of unusually high grade, are of relatively small dimensions, the longest shoot of ore in any instance not exceeding 150 ft., with an average width of 4 to 5 ft.; so that richness and size are here exemplified in inverse ratio. Nevertheless, it has already been found, in one instance at least, that these deposits are workable at considerable profit, and were it not for the wet nature of the country and heavy influx of water into the mines, they would be veritable bonanzas in a small way. . . .

At Trial Bay, on the west coast, little exploration or development work has been done as yet. Within a short distance of the shore a hill of nickeliferous serpentine rises to a height of over 300 ft., and extends inland for some distance. Three adits, each about 100 ft. long, have been driven into the hill from different points of the compass. These adits have been sampled throughout their length, and samples have also been taken of the rock on the surface; the assays of the samples range from 0.34 per cent. to 0.83 per cent. Ni, their average being 0.51 per cent. The ore in the serpentine is said to be niccolite (NiAs), and to be disseminated in grains visible to the naked eye. In one of the adits a vein of high-grade ore consisting of garnierite, was intersected; this was sampled across a width of 12 ins. and assayed 13.35 per cent. Ni. The place of origin of the garnierite deposited in the vein is seen to be the enclosing rock that is impregnated with nickel, the garnierite being a secondary deposit of hydrous silicate of the metal, resulting from denudation of the serpentine and sub-aerial agencies.

The Trial Bay formation can be compared to that of New Caledonia, which is marked by the presence of nickeliferous peridotite changed into serpentine, and the occurrence of silicate of nickel as a secondary mineral On the other hand, the Trial Bay nickel deposit bears no resemblance to that at Dundas, either in form or origin, though they both hold a common relationship to the serpentine, which is in one case impregnated with the metal, while in the other it does not appear to be so. It is worth noting that the sampling of one of the Trial Bay adits in the serpentine gave an assay of 0.83 per cent Ni, and that the niccolite ore in the hill is amenable to water-concentration. Whether any portion of the metalliferous serpentine hill could be worked profitably as a low-grade proposition remains to be demonstrated. The garnierite deposits offer an additional inducement to further exploration of what may prove to be the most important occurrence of nickel in Tasmania. As regards local conditions, the Trial Bay deposit is without railway connection to any other place in the island, and in the matter of transport of ore to Europe, would be in a worse position than Dundas, as Trial Bay is a shallow open roadstead, so that all ore would need to be loaded into coasting vessels and taken to the ports of Strahan or Burnie for shipment to Europe by way of Melbourne or Sydney.[1]

It may be added that chromiferous iron ores, somewhat like those of Greece and Cuba, occur in Tasmania.[2]

UNITED STATES

While nickel ores have been found in numerous localities in the United States, this country's resources in the metal are comparatively unimportant. During the

[1] G. A. White, Mining Magazine, February, 1915, pp. 103-105.
[2] Journal Iron and Steel Inst., 1892.

last few years the production of nickel from domestic ores has come from the refining of blister copper, although the United States is the world's largest refiner of nickel. As shown on other pages of this Report, much the greater part of the nickel-copper matte produced at Sudbury and a minor part of the New Caledonia nickel are refined in the United States.

The following quotation from a recently published article gives a fair summary of the conditions in the United States as regards resources in nickel, and two other metals, manganese and chromium, that are of much importance in alloy steels:—

The position of the United States in times of possible stress, as to supplies of the three most common steel-hardening metals, manganese, nickel and chromium, is not altogether reassuring. Our production of manganese and chrome ores has increased considerably under the stimulus of abnormally high prices in 1915 and 1916. In fact, the production of pure manganese ores in 1916 amounted to nearly 27,000 tons, against 9,000 in 1915. Still it is very far from filling our domestic needs. A timely attempt has been made recently by the United States Geological Survey to catalogue the occurrences of possible supplies of nickel ores, which, though not rich enough to use under ordinary conditions, might serve as emergency supplies. The result of this survey is about to be published. Aside from sporadic and poor deposits of nickel-bearing pyrrhotite, low-grade oxidized ores are known to exist, but it may well be doubted whether any process could be devised to treat such ores effectively. May we hope for discoveries of new deposits? It is possible, but doubtful. Areas of gabbro, like that of Duluth, and those of serpentine, as in California, should be closely scanned. A possible source of nickel which has recently attracted some attention is found in the iron ores of Mayari, Cuba. These limonite ores, which are derived from the weathering of serpentine, average about 0.6 per cent. nickel oxide, and experiments have been carried out recently looking toward the extraction of this nickel. It is said to have been ascertained that while most of this nickel is present as a hydrous silicate, there is a smaller part which is insoluble, and it is suspected that nickel oxide may be present. It is also well possible that in some parts of Cuba larger deposits, like those of New Caledonia, may still be found.

On the whole the situation is discouraging, and this also applies to manganese and chromium. There is no use looking for chromium except in areas of serpentine, and all deposits so far found in the United States have been spotty and small. Three thousand tons of ore produced against seventy-six thousand tons imported—that tells the story.

Manganese is more widespread, and many old mines, especially in Virginia, are being reopened. There are some promising low-grade iron-manganese ores, but the pure and high-grade manganese dioxide is very scarce. Such material is used, among other things, for dry batteries, and it is said that manufacturers of these have found it very difficult to obtain a supply. Aside from the unique oolitic ores of southern Russia, the manganese deposits seem to thrive best under conditions of tropical weathering such as do not obtain in this country.

Cuba is rich in serpentine. There is also much manganese, and this southern neighbour of ours could possibly help us out quite a little in case of all three of these necessary metals.[1]

The catalogue of the occurrences of nickel ores by the United States Geological Survey, referred to in the preceding quotation, has been published.[2] It gives an interesting epitome of the occurrences. The following extracts from the publication contain the introductory and other notes together with the description of the Missouri deposits. These deposits are of most interest at the present time since preparations are being made for resumption of work in extracting nickel, cobalt and copper, in addition to lead, from them. The old plant at Fredericktown has been remodelled and additions made. It is expected that the production will soon be at the rate of 800 to 1,000 tons of nickel a year. The property is controlled by a Canadian company. The ore to be treated for nickel is said to contain

[1] Eng. and Mining Journal, New York, Jan. 20, 1917.
[2] Nickel in 1915, Min. Res. U. S., 1915, Part I, pp. 743-766, published January, 1917.

approximately the following percentages of metals, lead, less than 2; copper, 2.5; nickel, 0.9; and cobalt, 0.5.

No nickel ores are known to have been mined in the United States in recent years, but an equivalent of 822 short tons of nickel was saved in 1915 as a by-product in the electrolytic refining of copper. Of this output the larger part was marketed as metallic nickel and the smaller part was contained in hydrous nickel sulphate.

What part of this nickel came from American pig or blister copper and what part from foreign copper is uncertain, but it is roughly estimated that American ores produced between one-half and two-thirds of the whole. The foreign copper came from many countries and from every continent. The companies reporting a production were the American Smelting & Refining Co, Nichols Copper Co., Raritan Copper Works, and United States Metals Refining Co.

The great bulk of the nickel supply of the United States has been drawn for years from Canada. During 1915 smaller quantities were imported from New Caledonia, Australia, and Norway.

During the general stock-taking which has been going on in the United States during the last year many questions as to the country's resources in nickel have been asked, and in order to answer these questions and to show what nickel and nickel ore would be available in case of urgent need and shortage of supplies from other countries, the information available on the deposits of the United States has been epitomized in this paper.

The nickel deposits of the United States are small compared with the unrivalled deposits at Sudbury, Canada, but they have in the past made some production and will probably do so again. Nickel in quantities sufficiently large to excite attempts to exploit the deposits on a commercial scale has been found in California, Colorado, Connecticut, Idaho, Missouri, Nevada, New Mexico, North Carolina, Oregon, Pennsylvania, Virginia, and Washington under very diverse conditions and smaller deposits have been found in other States . . . .

During 1915 there was no known market for nickel ores in the United States. The large smelting companies bought only gold, silver, lead, zinc, and copper ores, and if nickel were present no allowance was made for it. As the nickel can be smelted with the copper into matte and can be separated in electrolytic refining and as nickel is now being saved by the refineries, it would seem that the purchase of nickel ores might be made mutually profitable to both smelters and miners.

No direct production of nickel from American nickel ores is known to have been made in this country since 1909, when the American Lead Co. operated a smelter at Fredericktown, Mo, for a short period. . . .

Missouri Deposits

The nickel deposits of Missouri are on the eastern side of the St. Francis Mountains, in the vicinity of Fredericktown, and on the Mine La Motte property, in Madison County Here, according to Winslow, galena is disseminated through a Lower Silurian dolomite now known as the Bonneterre (Upper Cambrian) limestone. The dolomite grades into sandstone, which in some places contains glauconite. It is underlain by an impure sandstone, also of Cambrian age, and this sandstone in turn rests on Archean granite and porphyry.

Here and there galena is disseminated through the dolomite and in places also considerable pyrite, chalcopyrite, and some nickel and cobalt sulphides, the latter probably combined in the mineral linnæite. The sulphides, other than galena, are found in greatest quantity in the lower part of the workings, next to and in the sandstone, especially near the granite and porphyry.

The quantity present varies considerably in the different workings. The mines have generally been operated for lead, and nickel and cobalt have been produced as by-products, except from the mines worked by the North American Lead Co. Genth states that the ores from Mine La Motte had been used as a source of nickel and cobalt oxides for a number of years prior to 1857. In the milling of the lead ores the sulphides of iron, copper, nickel, and cobalt which were saved were thrown aside, though a considerable percentage seems to have been lost in the tailings.

At one time the Mine La Motte ores were smelted to matte at the mine and the matte was sold to the refinery at Camden, N.J, and to others abroad. . . .

The North American Lead Co. erected a smelter in 1906 for treating the sulphides which had accumulated on its own and adjoining properties and also the ores as mined. In 1907, 2,731 pounds of cobalt oxide were made. In 1909, 83,394 pounds of cobalt oxide, 328,403 pounds of nickel, 8,214 tons of nickel and cobalt concentrates, 600 tons of copper, and 1,353 tons of lead concentrates were produced. In 1908, a body of ore 400 or 500 feet from the granite was 12 feet thick, and was said to carry 10 per cent. copper, 4 per cent. nickel and cobalt, and 4 per cent. lead. This ore had been reached by a long drift in which

the ore had been 1 to 2 feet thick, gradually increasing in thickness to the point noted. The company's affairs later became so involved that the property was sold at a forced sale in 1910 and has since remained idle. Plans for again starting work have repeatedly been reported.

Besides the properties named, those of the Hudson Valley Lead Co., Madison Lead and Land Co., 4 miles from Fredericktown, and the Jackson Revelle Co., 8 miles south of Fredericktown, are said to carry similar nickel deposits. From the meagre data at hand it seems probable that some hundreds of tons of nickel per year can be produced, with possibly one-fourth to one-third as much cobalt and several times as much copper.[1]

Other Deposits

It is unnecessary to say much concerning other deposits of nickel-bearing ores in the United States, all of which are lying idle and, moreover, are described in various publications which are readily accessible. But it may be said that all classes of nickel ores have been found, with the exception of laterite or nickeliferous iron deposits, such as those of Cuba. Silicate ores are represented by those of Webster, North Carolina, and Riddle, Oregon. Arsenical ores, associated with native silver and carrying cobalt and nickel, have been found in small quantities at Silver Cliff, Colorado, and Bullards Peak, New Mexico. Many years ago there was a small production of arsenical cobalt-nickel ores in Connecticut. Pyrrhotite-chalcopyrite deposits in which nickel occurs in economic quantity are represented by the Gap mine, Lancaster, Pa., and Friday claim, Julian, Cal., and others. The Gap mine has been referred to on a preceding page. At one time it was an important producer, but, since the discovery of the New Caledonia and Sudbury deposits, ore bodies of its size and character have become of little economic interest.

Imports and Exports

Nickel ores and nickel matte are specifically exempted from duty,[2] but imported "nickel, nickel oxide, alloy of any kind in which nickel is a component material of chief value, in pigs, ingots, bars, rods, or plates," must pay a duty of 10 per centum *ad valorem;* sheets of strips 20 per centum.[3]

Large quantities of nickel matte are imported into the United States, as shown by the following table:

Origin of Nickel Matte Imported in 1915.

	Quantity.	Nickel Content.
	Short Tons.	Pounds.
Matte from Sudbury, Ontario, ores	43,123	53,638,101[4]
Matte from New Caledonia ores	2,674	2,714,363
Total	45,797	56.352,464

Of the New Caledonia product 443 tons of high-grade matte, averaging 78 per cent. of nickel, came from France, 1,138 tons of low-grade matte, with 45.7 per cent. of nickel, direct from New Caledonia, and 1,093 tons, averaging 44.8 per cent. of nickel, were imported from New Caledonia via Australia. The only other

[1] Min. Res. U. S., 1915, Part I, pp. 743-766, published January, 1917.
[2] Tariff Act of Oct. 3, 1913, sec. 565. [3] Ibid, sec. 155.
[4] This quantity of nickel appears to be incorrect, but it is given in Min. Res. U. S., Part I, 1915, p. 759. Compare with figures in Chapter XII of this Report.

country from which unrefined nickel was obtained was Peru, 1 ton of ore containing 118 pounds of the metal being imported from that southern country.

Nickel alloys, pigs, bars, etc., were imported to the extent of 31,990 pounds, and the quantity of nickel oxide was 497 pounds.

The United States refines much more nickel than it can use, so that, though not a large producer, it is a large exporter. No nickel matte is known to be exported.

Exports of Nickel and Nickel Oxide.

Year.	Quantity.	Value.
1913	29,173,088	$9,686,794
1914	27,595,152	9,455,528
1915	26,418,550	10,128,514

The nickel content of salts and metallic nickel produced in the electrolytic refining of copper is given as 822 tons in 1915, of which between one-half and two-thirds is estimated to have come from United States ores. This quantity appears to be too low. Accurate statistics of such productions are difficult to obtain.

The American Smelting and Refining Company produced 560 tons of refined nickel in 1915, and 612 tons in 1916.[1]

[1] Eng. and Min. Jr, March 17th, 1917, p. 471.

CHAPTER V

Properties and Uses of Nickel and Its Compounds

METALLIC NICKEL

Physical Properties

Appearance, Colour, Etc.:—Nickel is a lustrous, silver-white metal having a slight steel grey tinge, which is very noticeable on comparing the metal with silver. It is more brilliant than platinum, and is sufficiently hard to take a fine polish. Its atomic weight is 58.68 (Oxygen = 16) and its specific gravity, when cast, 8.35, which becomes increased to 8.6-8.9 by rolling, hammering or other mechanical treatment.

Mechanical Properties:—Cast nickel approaches soft steel in hardness. It is very malleable and ductile, and can be rolled into sheets of extreme thinness (0.0008 inch) and drawn into wire of remarkable tenuity (0.0004 inch diameter). Its malleability and ductility are diminished by the presence of carbon, manganese, arsenic, sulphur or nickel oxide.

At a white heat, it can be welded to itself, to iron and to various alloys.

According to Copaux[1] the hardness of nickel, containing only 0.05 per cent. of non-metallic impurities, is 3.5 of Moh's scale, say about 80 Brinell scale, and the breaking stress, 42 kilos. per sq. mm.

Kollman gives the tenacity of nickel containing 0.05 per cent. of magnesium as 38.9 tons per sq. inch; whilst for wrought nickel, after annealing, Shakell gives 42.4 tons per sq. inch as the tensile strength.

The effect of annealing on the tensile strength of hard drawn wires of nickel has been studied by L. Guillet.[2]

The results of a large number of mechanical tests show that in all cases, the temperature of complete annealing, as indicated by a rapid fall in the maximum strength and elastic limit, and a rapid increase in percentage elongation, is practically independent of the amount of cold work. These temperatures for nickel are 700° C. to 750° C.

Guillet[3] found that, although the tensile strength, elastic limit and elongation of hardened nickel were not affected by heating the metal to below 400° C., a slight deflection occurred at about this temperature and a marked alteration (chiefly as regards elongation) between 700° and 750° C.; he also concluded that, contrary to generally accepted views, the influence of time on the effect of annealing was relatively slight.

Action of Heat:—Copaux[4] gives 0.108 as the specific heat of nickel between 20° and 100° C., and 0.0061 as the coefficient of expansion between 0° and 20° C.

[1] Comptes Rend., 1905, 140, 657.
[2] J. Inst. Metals, 1913, I, p. 220.
[3] Rev. Met., 1913, 10, 665-676.
[4] Loc. cit.

By examining a number of specimens of commercial nickel, of dates from 1891 to 1911, Guillaume[1] found the expansibility of the modern metal to be distinctly lower than that of earlier specimens; but concluded that, when nickel standards of length are used, correction for temperature within a range of 20° C. may be neglected unless extreme accuracy is required.

Nickel is difficultly fusible, its melting point, according to Moissan, being about 1,500° C, but, as in the case of iron, the melting point is very considerably lowered by the presence of carbon.

Copaux gives 1,470° C. as the melting point of pure nickel; while Burgess and Waltenberg[2] give the probable melting point of the pure metal as 1,452° ± 3° C. The latter temperature (1,452° C. or 2,646° F.) is confirmed by Ruff, Bormann and Keilig[3] and is adopted by the U. S. Bureau of Standards.

According to Moissan,[4] nickel may be distilled in the electric furnace, the distillate having the same properties as the finely divided metal. It is not so volatile as manganese, but more volatile than iron or chromium.

Magnetic Properties:—Nickel is magnetic at ordinary temperatures, its magnetic power being about two-thirds that of iron; but it becomes non-magnetic at high temperatures, the transition occurring at about 350° C.

The polymorphic change to which this loss of magnetic power is ascribed, has been the subject of investigation by several workers, by whom the transformation temperature has been determined with results varying from 340° to about 360° C.

Werner[5] states that the heat of the transformation is about 0.013 calorie per gramme, and that the change is unaccompanied by any alteration in the volume of the metal.

Electrical Properties:—The electrical conductivity of nickel is about 12.9 if that of silver be taken as 100. Copaux[6] gives 6.4 microhms /c.c. as the specific electrical resistance of the metal at 0° C.

Chemical Properties

General Behaviour:—Nickel in the massive state does not readily tarnish in the air at ordinary temperatures, but at a red heat becomes coated with the greyish-green oxide.

If heated, nickel wire burns in oxygen like iron; it also becomes incandescent in nitric oxide at 200° C., and when prepared by reduction, is pyrophoric. Nickel decomposes steam at a red heat, but only slowly. Acetic, citric, tartaric and oxalic acids have little or no action on nickel unless they are left in contact with the metal for a long time; and caustic alkalis may be fused in nickel vessels without any change taking place. The metal is not affected by fresh or sea water; and dissolves very slowly in hydrochloric or sulphuric acid, but rapidly in nitric acid or aqua regia.

[1] Comptes Rend., 1912, 154, 748-751.
[2] J. Washington Acad. Sci., 1913, 3, 371-378.
[3] Z. anorg. Chem., 1914, 88, 365-423.
[4] Comptes Rend., 1906, 142, 425.
[5] Z. anorg. Chem., 1913, 83, 275-321.
[6] Loc. cit.

Passivity of Nickel:—In contact with concentrated nitric acid, nickel becomes passive like iron; when dropped into fuming nitric acid it may be violently attacked, may become passive, or may be disintegrated to a grey magnetic powder.[1]

Schmidt and Rathert[2] report that nickel can remain passive when subjected to friction in an atmosphere of hydrogen, under conditions in which no oxide film could remain. They consider the results of their investigation to establish the validity of the hydrogen-catalysis theory of activity, according to which the passive metal is in a similar condition to that of water in the absence of air, which does not boil even when its vapour pressure is equal to that of the super-incumbent atmosphere. Just as small quantities of air initiate the rapid evaporation of large quantities of liquid, so, they consider, a small quantity of hydrogen can "activate" large quantities of nickel.

In order to ascertain whether pure nickel may be considered active, and the passive state be attributed to the presence of some retarding catalyst, or conversely, whether the pure metal may be considered passive and the active state attributed to the presence of an accelerating catalyst, a series of experiments was conducted by Grave.[3] As the result of the investigation, the first theory was found to be untenable; it is therefore considered highly probable that pure nickel is passive, and only becomes active in the presence of hydrogen ions which act as catalysts in the process of formation of ions of the metal.

Byers and Morgan[4] placed an anode of nickel and a platinum cathode in a test-tube containing an electrolyte, and measured the current density required to render the anode passive, both under ordinary conditions and when the tube was placed between the poles of an electro magnet. The current density required to render nickel passive, was materially increased when the metal was in the magnetic field.

From experiments on the behaviour of nickel in mixtures of sulphuric acid and hydrogen peroxide, D. Reichenstein[5] concludes that there are two forms of passive nickel; the passivity being due to a high concentration of adsorbed molecular oxygen in one case, and to a high concentration of adsorbed atomic oxygen in the other.

Corrosion of Nickel:—Jorissen[6] reports that nickel is hardly attacked by air, moisture, sea water and dilute hydrochloric and sulphuric acids.

According to the same author, the order of the metals when arranged according to their potential (referred to the hydrogen electrode) in normal solutions of their salts is:—Magnesium, aluminium, manganese, zinc, cadmium, iron, cobalt, nickel, tin, lead, hydrogen, copper, bismuth, antimony, mercury, silver, platinum and gold, those preceding hydrogen being positive and those following it, negative.

The action of dilute solutions of acids, alkalis and salts on nickel (among other metals) was investigated by A. J. Hale and H. S. Foster,[7] who determined

[1] Hollis, Proc. Camb. Phil. Soc., 1904, 12, 253.
[2] Faraday Soc., Nov. 12, 1913.
[3] Z. physik. Chem., 1911, 77, 513-576.
[4] J. Amer. Chem Soc., 1911, 33, 1757-1761.
[5] Z. Elektro-chem., 1915, 21, 359-372.
[6] Comptes Rend, Internat. Pharmaceut. Congress, 1913; Engineering, Oct. 23, 1914, 512.
[7] J. Soc. Chem. Ind., 1915, 464.

the loss in weight sustained by similar pieces of the metal on immersion in the various liquids, for periods up to 28 days. Cold hard-rolled and polished commercial sheet nickel was employed, the total area of each piece being 1 sq. d.m. The solutions were of n/5 strength and were used at 17°—20° C. In one set of experiments, each specimen was immersed in 500 c.c. of the solution for seven days, the liquid being renewed each day; in another set, each sample was immersed in 500 c.c. of the solution for 28 days without renewal of the liquid. The losses in weight sustained by the specimens in the 7 and 28 days tests were as follows:—

Corrosion Tests of Nickel

Specimens immersed in	Loss of weight in 7 days (solution renewed daily) Grammes.	Loss of weight in 28 days (solution not renewed) Grammes.
HNO_3 (n/5)	4.2	2.1
HCl "	0.25	0.45
H_2SO_4 "	0 25	0.40
$MgCl_2$ "	0.05	0.10
NaOH "	0.00	0 00
$CaCl_2$ "	0.08	0.05
NaCl "	0 00	0 00
NH_4OH "	0 00	0 00
Na_2CO_3 "	0.00	0.00

In his researches on the relative basicity of metals (i.e., their power to replace one another) in non-aqueous solutions, L. Kahlenberg[1] found that metallic nickel was without effect on solutions of copper, manganese, chromium, iron and cadmium oleates, and copper palmitate, in various organic solvents, either at ordinary temperatures, or at 100° C.

According to M. Vuk,[2] the discordant results obtained in experiments on the action of acids upon nickel cooking utensils are due to the nature of the nickel. Pieces of nickel of the same area were heated on the water-bath with 5 per cent. acetic acid for 2½ hours, and the milligrammes of metal dissolved per sq. m. were determined electrolytically, with the following results:—wrought, 15.5 to 16.9; cast, 25.5 to 28.8; electrolytic, 30.6 to 30.8; drawn, 33.1 to 39.0; and Berndorf "pure" nickel, 61.4 to 65.4 mgrms. It may be mentioned that the last named is the material commonly used for spinning into hollow-ware for ornamental purposes, cooking utensils, etc. It contains a small amount of magnesium, added to improve its rolling and spinning quality.

Absorption of Gases by Nickel, and Their Effect. Hydrogen is occluded by nickel at temperatures above 200° C. in quantity increasing with the temperature; but very different results have been obtained by Bayer and Altmayer, and Sieverts[4] for the amount actually occluded.

[1] Trans. Amer. Electrochem. Soc, 1910, 18, 103-107.
[2] Z. Untersuch. Nahr. Genussin., 1914, 28, 103.
[3] Ber. 1908, 41, 3062.
[4] Z. physik. Chem., 1907, 60, 129.

In determining the solubility of hydrogen in molten nickel at temperatures from 400° to 1,600° C. and pressures up to 1.5 atmospheres, Sieverts[1] found that the amount of gas absorbed under given conditions of temperature and pressure is independent of the amount of metallic surface, a true solution of the gas being formed. The solubility of the gas increases with the temperature, and the metal "spits" on solidification in an atmosphere of hydrogen, about 12 times its volume of the gas (at 1,450° C. and 760 mm.) being given off; the solidified metal contains cavities in which hydrogen may still be retained. It is only by very rapid cooling that any considerable quantity of hydrogen can be retained in the metal at ordinary temperature.

Molten nickel absorbs carbon monoxide which is given off on cooling, unsound castings full of blow-holes being produced. Carbon monoxide may also be generated in the molten metal by the action of carbon on nickel monoxide, both of which constituents the metal may contain. Nickel has the power of dissolving its monoxide, forming a eutectic similar to that formed by copper with cuprous oxide, and with the same result, i.e., brittleness of the metal.[2]

The unsoundness due to blow-holes and the brittleness caused by nickel oxide can, however, be removed by the addition of small quantities of magnesium to the molten metal (Fleitmann's process) and perfectly sound and malleable castings thus obtained. Manganese, added to the extent of one to three per cent. is also stated to act as a purifier, and to improve the quality of the metal. This matter and others connected with the purification of nickel are dealt with in the Chapter on Refining Processes.

Carbon is also absorbed by molten nickel. Ruff, Bordmann and Keilig[3] found the carbon content of carbon-saturated nickel to be 6.3 per cent. and the boiling point of the latter at 30 mm. pressure, to be 2,490° C.

Ruff and Martin,[4] in determining the solubility of carbon in nickel between 1,550° and 2,100° C. found a maximum carbon content of 6.42 per cent in the metal (corresponding to the formula Ni_3C), the whole behaviour of the nickel-carbon series being similar to that of the iron-carbon alloys.

H. C. H. Carpenter[5] has published some instructive particulars as to the disintegration of nickel wire when used as a resistance in place of platinum in electric furnace work. He attributes the fibrous structure, brittleness and other physical changes in the wire during such use, to the absorption of gases, and states, inter alia, that nickel made electrolytically would probably be most suitable on account of its being less liable to contain occluded or combined gases.

Commercial Nickel and Effect of Impurities

The nickel of commerce, with the exception of that obtained by the Mond process, is generally impure. It frequently contains only about 98.0 to 98.5 per cent. of nickel, often as much as 1.0 per cent. of cobalt, 0.3 to 0.6 per cent. of

[1] Z. physik. Chem., 1911, 77, 591-613.
[2] J. Institute of Metals, 1912, V. 8, p. 326.
[3] Z. anorg. Chem., 1914, 88, 365-423.
[4] Metallurgie, 1912, 9, 143-148.
[5] British Association Meeting, 1906, and Collected Researches National Physical Lab., Vol. III, 1908, pp. 259-268.

iron, a little copper, silicon and magnesium. Arsenic, sulphur and nickel oxide are also occasionally present; they cause brittleness in the metal, and diminish or destroy its properties of being rolled or drawn. Even 0.1 per cent, of arsenic or sulphur is injurious, Iron, too, hardens nickel, and if much is present, say 1.0 per cent., the metal is unsuitable for the manufacture of the best qualities of German silver. As has already been pointed out, nickel dissolves carbon and also nickel oxide. With 1.0 per cent. of carbon it is brittle, but with a higher percentage it is tough. When nickel contains both carbon and nickel oxide, carbon monoxide is produced on melting it, and the castings are full of blow-holes.

Nickel is commonly sold in the form of small cubes, or in discs known as "rondelles," or in granules. It is, however, largely sold in plaquettes weighing 25 or 50 lbs., as is the case with much of that shipped by the International Nickel Company, and in shot of various standard sizes according to the requirements of the trade, by the Mond Nickel Company.

The following are analyses of typical samples of commercial nickel: —

It is hoped that the table will not be quoted or reprinted without the explanatory notes, as a mere quotation of the tabulated results would be misleading.

ANALYSES OF COMMERCIAL NICKEL

No.	Nickel. p.c.	Cobalt p.c.	Iron p.c.	Copper p.c.	Carbon p.c.	Sulphur p.c.	Silicon p.c.	Manganese p.c.
1	99.30	"some"	0.39	0.07	0.09	0.01	0.07	....
2	97.30	1.20	0.49	0.08	0.14	0.02	0.30	....
3	99.10	0.40	0.30	....	0.05	....	0.10	0.05
4	99.29	nil	0.48	....	nil	0.025	0.042	....
5	98.60	trace	1.22	....	....	....	....	0.16
6	98.00	....	1.60	0.50	....	....	0.13	....
7	98.23	....	0.98	....	....	....	0.30	....
8 over	99.00	....	0.23	0.10	0.07	0.008	0.12	....
9	97.87	1.45	0.45	0.10	trace	0.05	0.19	....
10 about	98.00	1.60	0.75	0.05	....	....	....	....
11	99.25	....	....	....	....	....	....	....
12	98.75	....	0.50	0.10	....	0.01	....	....
13	99.08		0.46	0.10	0.05	0.024	0.05	....
14	99.8	....	....	....	....	....	....	....

The above analyses have been collected from various sources, and are fairly typical of the various brands on the market, and the range of purity common in brands used on the large scale. Several have been supplied to the Commission by the users, who do not wish their names or the names of the brands to be published. A dotted line means that the constituent has not been determined, but not that it is absent. Cobalt, when represented by a dotted line, is commonly included as nickel. In several cases, the metal has been produced from mixed ores derived from many far distant localities. The Norwegian nickel for instance, until some time after the war broke out, was obtained from Norwegian ore in admixture with ore from New Caledonia, Greece, Tasmania and even Egypt; some of the so-called New Caledonian nickel is similarly in part derived from ore from other localities. The analysis of the nickel described as "rondelles," may be taken as typical of the ordinary commercial discs and cubes of metal made from roasted bessemerized matte from New Caledonian or other ores, or sometimes from a mixture

of ores. It has been deemed best to give a considerable number of analyses, and all those quoted in the table are stated to be suitable for general use. It may be pointed out that, although extreme purity is essential in some cases, the less pure brands are equally suitable for many purposes, and are occasionally preferred on account of greater ease in alloying. The makers of some of the specially pure brands found great difficulty in disposing of their metal because its melting point was higher, or its speed of alloying with other metals was different from that of chemically inferior brands, with whose use the alloy makers were familiar.

It may be taken as a fact that, except for very special purposes, the premium on extreme purity is practically negligible, and that even larger amounts of impurity than are shown in the assays are commonly permissible. A considerably larger amount of copper or cobalt would, for instance, not usually be penalized.

It may be pointed out that the presence of manganese and magnesium in some samples is due to the deliberate use of manganese to remove impurities in the final purification of the nickel, or of magnesium in order to render the nickel more amenable to rolling, spinning, and drawing for direct production of metallic nickel ware.

Commercially speaking, the country of origin or the type of ore employed has practically nothing to do with the value of the final metallic nickel, although such an ore as that of New Caledonia may be taken as certain to yield—if smelted alone—a nickel free from copper but containing more cobalt than that from other largely worked deposits. Similarly, the nickel made from the oxide obtained from the ores of the Cobalt district, usually contains over one per cent. of cobalt, to which no objection is made by the trade. On the other hand, ores like those of Sudbury, which are rich in copper, still yield nickel free from copper when made by the Mond process, practically free from it when made electrolytically, and sufficiently free for almost all commercial purposes, when made by the Orford process employed by the International Nickel Company. Although trade prejudice has in the past interfered seriously with the development of the Canadian nickel industry, such prejudice has now entirely disappeared, and nickel sells entirely on its quality or brand, regardless of the nature of the ore which produced it.

The prejudice in favour of a special "brand" is based on regularity of composition, and the reputation of the producer is so bound up with maintenance of quality that such prejudice is by no means undesirable. "Mond" nickel may be taken as chemically pure for all practical purposes. It invariably contains over 99.8 per cent. of nickel, and is free from more than minute traces of cobalt and copper, and from more than ordinary "traces" of iron, silicon, etc. Electrolytic nickel may or may not be of extreme purity. It usually contains cobalt, and traces or even appreciable quantities of such impurities as copper and iron which may have been present in the original ore, and electrolytic processes of refining permit of the production of nickel of various grades, according to market requirements.

The ordinary nickel produced by the International Nickel Company, i.e., by far the larger proportion of the world's output, may be taken as averaging about 99 per cent. nickel (including a small proportion of cobalt), the remainder being

mainly copper and iron. The company also produces high quality electrolytic nickel in considerable quantity, so that it supplies demands for both extreme purity and ordinary commercial quality.

The Samples Analysed

The following statement describes the samples whose analyses are given in the table:—

1. "Special" brand.
2. Average brand.
3. "One of the best brands."
4. "Pure nickel." Kalmus & Harper state that this specimen showed Brinell hardness 83.1, tensile breaking load 18,000 lbs. per sq. in. and melting point 1,452 degrees C.
5. Nickel wire made by the Vereinigte Deutsche Nickel Werke (formerly Fleitmann Witte & Co.). This nickel is freed from sulphur with the aid of manganese, and is specially suitable for rolling, stamping, spinning and drawing. An addition of magnesium is commonly made to render it more amenable to such treatment, especially for the manufacture of cooking and other nickel ware.

6 and 7. Nickel from New Caledonian ore. It may be taken for granted that 6 was not entirely produced from that ore, although sold as such.

8. Rondelles and cubes of high quality for making nickel silver, etc.
9. Nickel made by Basse and Selve.
10. Nickel from the Deloro Mining and Reduction Company, Limited. It is produced from the mixed cobalt-nickel ore of the Cobalt silver camp, and the somewhat high proportion of cobalt present could be reduced if market requirements rendered it necessary.
11. Rondelles (discs) and cubes of nickel made at Erdington near Birmingham, England, from roasted New Caledonian matte. Similar metal is made by the Anglo-French Nickel Company at Hafod Isha in Wales, also from New Caledonian matte.
12. Electrolytic nickel made at the Kristianssands Nikkelraffineringsverk, Norway, by the Hybinette process.
13. International Nickel Co. The analysis given is that of one shipment only. The ordinary brand may be taken as containing about 99 per cent. of nickel, including a small proportion of cobalt. This company also sells electrolytic nickel of greater purity.
14. Mond nickel. This is always of extreme purity. It contains at least 99.8 per cent. of nickel and, for all practical purposes may be considered chemically pure, and free from more than traces of cobalt, copper and iron. Stahl und Eisen gives, as a typical analysis, nickel 99.78, iron 0.161, carbon 0.06, "silica" 0.027, cobalt 0.013 per cent.

Nickel Alloys:—These are described in the Chapters dealing with Nickel Steel and with the Non-ferrous alloys of nickel. Their great and increasing importance has necessitated their treatment separately, rather than along with the properties of the metal itself.

Compounds of Nickel

Oxides and Hydroxides

The chief oxides of nickel are the monoxide, NiO, and the sesquioxide, Ni_2O_3.

Nickel monoxide, NiO, occurs native as bunsenite, and may be prepared by strongly heating the hydroxide, $Ni(OH)_2$, carbonate, $NiCO_3$, or nitrate $Ni(NO_3)_2$ It is a green crystalline powder, which turns yellow on heating, and is easily reduced to the metal when heated in hydrogen. The ordinary salts of nickel are derived from nickel monoxide; they are, in general, yellow when anhydrous, and emerald green when hydrated or in solution.

Nickel sesquioxide, N_2O_3, is a black powder obtained by gently heating the nitrate or carbonate in air. It is decomposed by heat, and is probably a combination of the monoxide and the peroxide, $NiO.NiO_2$.

Nickel peroxide, NiO_2, is obtained in the hydrated form by the action of hydrogen peroxide on nickel salts[1]. An oxide regarded as NiO_4 was obtained by Hollard[2].

Tubandt and Reidel[3] suggest that nickel dioxide or peroxide, NiO_2, is the only true higher oxide of nickel, and that Ni_2O_3 and other oxides are to be regarded as compounds of the dioxide NiO_2 with the monoxide NiO. They also hold that all experiments on the oxidation of nickelous salts which have been assumed to result in the formation of solutions containing salts of trivalent nickel, probably only produce colloidal solutions of the peroxide; and adduce evidence in support of their contentions.

Sabatier and Espil[4] state that a suboxide of nickel can be obtained by passing carefully purified hydrogen over heated nickelous oxide, the velocity of reduction depending on the nature of the oxide, the rapidity of the hydrogen current, and the temperature. The authors give results obtained by reduction at temperatures between 155° and 250° C. with hydrogen currents varying from 6 to 24 c.c. per min. and times from 1 to 163 hours, these results showing that a fairly rapid reduction first occurs to a suboxide, which is then reduced to metal at a much slower rate. The probable formula of the suboxide, is given as Ni_4O, corresponding to the compound $Ni_4(NO_2)_2$. The reduction is retarded by traces of moisture.

Nickelous hydroxide, $Ni(OH)_2$, is formed as an apple-green precipitate when a nickel salt is treated with an alkali hydroxide.

Paal and Brunjes[5] prepare nickelous hydroxide sols by treating a nickel sulphate solution with a solution of sodium protalbinate or lysalbinate, and dissolving the precipitate in dilute sodium hydroxide solution.

Nickel trihydroxide, $Ni(OH)_3$, is obtained as a black precipitate when a nickel salt is warmed with alkali hypochlorite, or when chlorine is passed through a suspension of nickelous hydroxide $Ni(OH)_2$ in water. According to Bellucci and Clavari,[6] this precipitate is the hydrated dioxide $NiO_2 + H_2O$.

[1] Pellini and Meneghini, Z. anorg. Chem., 1908, 60, 178.
[2] Comptes Rend., 1903, 136, 229.
[3] Z. anorg. Chem., 1911, 72, 219.
[4] Comptes Rend, 1914, 158, 668.
[5] Ber., 1914, 47, 2200.
[6] Gazz. Chim. Ital., 1905, 14, ii, 234; Atti. R Accad. Lincei., 1907 (v.), 16, i, 647.

Nickel bromide, $NiBr_2$ is produced when finely-divided nickel is heated in bromine vapour. It sublimes in golden scales, and is very hygroscopic, forming a trihydrate, $NiBr_2$, $3H_2O$. The accepted equivalent of nickel rests largely upon results obtained in the analysis of anhydrous nickel bromide.

Ducelliez and Raynaud[1] state that nickel combines readily at the ordinary temperature with dry bromine in the presence of ether, forming $NiBr_2$, $C_4H_{10}O$, a yellow compound from which the anhydrous bromide is readily obtained by heating.

Nickel carbonate, $NiCO_3$, is best obtained by heating a solution of nickel chloride with calcium carbonate at 150° C. It forms pale-green, microscopic rhombohedra.

A hexahydrate, $NiCO_3$, $6H_2O$ is produced by mixing nickel nitrate solution with sodium bicarbonate, and saturating the cold solution with carbon dioxide; it readily loses water. The pale-green precipitates obtained by adding alkali carbonate to a nickel salt are basic carbonates of variable composition.

Nickel chloride, $NiCl_2$, is formed when finely-divided nickel is warmed in chlorine. It can be sublimed, and forms golden scales. It dissolves in water with the evolution of heat, and a green hexahydrate, $NiCl_2$, $6H_2O$, can be crystallized out from the solution. The anhydrous chloride readily absorbs ammonia, forming an almost white compound, $NiCl_2$, $6NH_3$, which dissolves easily in water. Nickel chloride is soluble in alcohol.

Nickel cyanide, $Ni(CN)_2$, is obtained as an apple-green precipitate by adding potassium cyanide to a solution of a nickel salt. It is readily soluble in excess of potassium cyanide and, from the solution, the double salt $Ni(CN)_2.2KCN$ can be crystallized. This salt is readily decomposed by dilute acids; no double cyanides are known corresponding to ferro and ferri-cyanides.

According to Rossi[2], the results of determinations of the electrical conductivity of solutions of nickel chloride to which increasing quantities of potassium cyanide were added, indicate that the double salt formed is $K_2Ni(CN)_4$.

Nickel fluoride, NiF_2, forms green prisms[3]. It is soluble in water with formation of a trihydrate, $NiF_2.3H_2O$.

Nickel iodide, NiI_2, forms black scales. The hexahydrate $NiI_2,6H_2O$ is a bluish-green, very hygroscopic, crystalline substance.

Nickel nitrate, $Ni\ (NO_3)_2.6H_2O$, is a green salt which crystallizes in monoclinic tablets. It dissolves in twice its weight of cold water and is also soluble in alcohol. Tri- and monohydrates are also known.

Nickel oxalate has the formula $NiC_2O_4.2H_2O$. Dodgson[4] obtained a green solution on boiling this compound with an approximately 2N solution of sodium carbonate. On filtering this solution and allowing it to remain for about 24 hours, green crystals were obtained consisting of the double oxalate of nickel and sodium, $NiC_2O_4,Na_2C_2O_4.8H_2O$; but the green solution could not be crystallized by evaporation aided by heat. The reaction between nickel oxalate and sodium carbonate is obviously a balanced one, the actual conditions of equilibrium depending on the relative masses of the sodium carbonate and nickel oxalate present; nickel oxalate cannot be completely converted into carbonate by the action of a sodium carbonate solution.

[1] Comptes Rend., 1914, 158, 2002-2003.
[2] Gaz. Chim. Ital., 1915, 45, I., 6-10.
[3] Poulenc, Comptes Rend., 1892, 114, 1426.
[4] Chem. Soc. Proc., 1911, 27, 260.

Nickel sulphate, $NiSO_4$, is formed in solution when nickel, or the hydroxide or carbonate, is dissolved in dilute sulphuric acid. At ordinary temperatures, the salt crystallizes as the green heptahydrate, $NiSO_4,7H_2O$, isomorphous with magnesium sulphate. At 50°—70° C. the hexahydrate, $NiSO_4,6H_2O$, separates in monoclinic crystals, and a hydrate of the same composition separates at ordinary temperatures from acid solutions, but the crystals are tetragonal pyramids.

The hydrated sulphate loses water at 100° C. forming the monohydrate, $NiSO_4H_2O$, and at 280° C. the anhydrous sulphate is left. The latter absorbs ammonia, forming a pale violet powder of the composition $NiSO_46NH_3$. The compound $NiSO_44NH_32H_2O$ crystallizes in dark blue tetragonal prisms from concentrated solutions of the sulphate in ammonia. The solubility of nickel sulphate in water, expressed as parts of the anhydrous salt per 100 parts of water, is 30.4, 37.4, 41.0, 49.1, 52.0, 57.2 and 61.9 at 2°, 16°, 23°, 41°, 50°, 60° and 70° C. respectively.

Hofman and Wanjukow[1] find that when nickel sulphate is heated in a tube open at both ends, decomposition commences at 708° C., the product being NiO. Hofman's General Metallurgy, 1913, p. 99, states that anhydrous $NiSO_4$ begins to desulphatise at 702° C., and that decomposition is energetic at 764° C.

Nickel sulphate forms numerous double sulphates with the sulphates of other metals. Of these, the most important is nickel ammonium sulphate, $NiSO_4.(NH_4)_2SO_4.6H_2O$, which is largely used in nickel plating and other processes. It is obtained by dissolving nickel or nickel monoxide in sulphuric acid, and adding ammonium sulphate to the concentrated acid solution. It is purified by recrystallization and forms short, monoclinic prisms. The solubility, expressed as parts of anhydrous salt per 100 parts of water, is 1.8, 5.8, 5.9, 8.3, 11.5, 14.4, 18.8 and 28.6 at 3.5°, 16°, 20°, 30°, 40°, 50°, 68° and 85° C., respectively.

Nickel arsenide, NiAs, occurs naturally as kupfer-nickel.

Nickel boride, NiB, has been made in the electric furnace[2], and forms brilliant prismatic crystals, of sp. gr. 7.39. It is decomposed when fused with alkali.

Nickel carbide, Ni_3C, has been shown by Briner and Senglet[3] to be formed and dissociated according to the equation, $3Ni + C \rightleftarrows Ni_3C$, the temperatures most favourable to formation and dissociation being about 2100° and 1600° C., respectively; dissociation is relatively slow at 900° C.

Nickel carbonyl, $Ni(CO)_4$. When carbon monoxide is passed over reduced nickel at 30°—80° C., combination occurs and a volatile carbonyl is formed[4]. It is a colourless liquid, boiling at 43.2° C. and solidifying at —25° C.; its sp. gr. is 1.3185 at 17° C.; and at 50° C. it has the normal vapour density. The carbonyl is soluble in organic media; and its vapour is very poisonous. At 180° C., the carbonyl is resolved into metallic nickel and carbon monoxide. The formation and subsequent decomposition of nickel carbonyl form the basis of the Mond process for the commercial extraction of nickel from its ores and products. Although of little direct importance, it is in consequence, one of the most interesting of the nickel compounds commercially, as it furnishes the means of producing nickel of great chemical purity from highly complex ores.

[1] Met. and Chem. Eng., 1912, 10, 172.
[2] Moissan, Comptes Rend., 1896, 122, 424.
[3] J. Chim. Phys., 1915, 13, 351.
[4] Mond, Langer and Quincke, Chem. Soc. Trans., 1890, 749.

Nickel dimethyl glyoximate is of importance as being one of the forms in which nickel is precipitated and weighed for purposes of assay. It is a bright-red, voluminous powder, obtained by the addition of an alcoholic solution of dimethyl-glyoxime to an ammoniacal solution of a nickel salt.

Nickel ethylenediamine. W. Traube[1] describes the reaction of nickel hydroxide with ethylenediamine to form a violet solution of a salt having the formula $Ni(C_2H_8N_2)_3.(OH)_2$.

Metallo-Compounds of Nickel

According to Pickering[2], nickel forms compounds which are closely analogous to the cupri-compounds, being characterized by great depth of colour and solubility, and by containing the metal as an ion, as proved by electrolysis.

Nickel phosphide, Ni_2P, is obtained in grey needles when nickel and phosphorous are heated in the electric furnace[3].

Nickel silicide, Ni_2Si, is prepared by heating an excess of nickel with silicon in the electric furnace until the greater part of the metal has been volatilized; and then dissolving away the remaining metal with dilute nitric acid. It is a steel-grey, metallic-looking powder of sp. gr. 7.2, and is attacked by aqua regia and by hydrofluoric acid[4].

Nickel sulphides. The monosulphide, NiS, occurs in nature as millerite. It is obtained in a black, hydrated form when a nickel salt is precipitated by ammonium sulphide, but cannot be precipitated in the presence of mineral acids, although, when once precipitated, it dissolves very slowly in dilute hydrochloric acid. Thiel and Gessner[5] consider that this anomalous behaviour of nickel monosulphide to dilute acids is due to its existence in three forms, all of which may occur in the precipitate obtained in ordinary analysis. The three modifications are polymerides, of which one is amorphous and the other two of different crystalline form.

Nickel subsulphide, Ni_2S, has been described by Mourlot[6]; and the sesquisulphide by Dewar and Jones.[7]

Copper-nickel sulphide:—Hayward[8] obtained heating and cooling curves of mixtures of Ni_3S_2 (the stable sulphide) and Cu_2S, showing that the system is eutectiferous between 25 and 90 per cent. Ni_3S_2, and that outside this range there is a series of solid solutions. The eutectic contains 77 per cent. Ni_3S_2 and solidifies at 778° C. The melting point of Ni_3S_2 is 794° C., and that of Cu_2S 1130° C. The molten mattes do not separate into layers, and there is no evidence of chemical compounds of the two sulphides. The absence of any liquation of nickel sulphide or copper sulphide from nickel-copper matte has also been recently pointed out by G. A. Guess and F. E. Lathe in a paper read at the summer meeting, 1916, of the American Institute of Mining Engineers.

[1] Ber., 1911, 44, 3319.
[2] Chem. Soc. Trans., 1915, 107, 942.
[3] Maronneau, Comptes Rend., 1900, 130, 656; cf Granger, ibid. 1896, 122, 1484; 1896, 123, 176.
[4] Vigouroux, Comptes Rend., 1895, 121, 686.
[5] Z. anorg. Chem., 1914, 86, 1-57.
[6] Comptes Rend., 1897, 124, 768.
[7] Chem. Soc. Trans., 1904, 211.
[8] Trans. Amer Inst. Min. Erg., 1915, 48, 141.

Nickel tannates:—While working with nickel hydroxide as a substitute for hide powder in tannin estimation, Puran Singh[1] examined the nature of the salts yielded by the interaction of nickel hydroxide and tannic acid. It was found impossible to prepare absolutely pure salts, but the results were regarded as showing the formation of only two theoretical salts, viz., the normal tannate, $(C_{14}H_8O_9)_2Ni$, containing 10.69 per cent. NiO, and $Ni_3(C_{14}H_7O_9)_2$ containing 27.53 per cent. NiO.

Uses of Nickel and Its Compounds

No country publishes official data as to the actual quantity of nickel used for special purposes such as the manufacture of steel, special iron and non-ferrous alloys, oxides, salts, etc. Like copper, nickel ores are commonly smelted far from the mine itself. The matte produced by this smelting is transported to a distance for final treatment or refining, and it is often difficult or impossible to trace the product to its ultimate source. Hence many of the published statistics, especially those which appear most definite, are unreliable, and many of them give merely the contents of nickel in the ore or matte imported or exported, and therefore indicate a higher recovery than is actually obtained.

The enquiries of the Commission have also been hampered on account of the secrecy imposed upon the collection and publication of statistics under war conditions, i.e., the necessity for forbidding publication for the time being, at any rate, of much of the knowledge which is in the possession of officials as to the amount of nickel used for any special purpose The statistics published in the United Kingdom at the present time also ignore altogether such materials as are purchased by the British Government for its own direct use; in other words, it would be impossible to usefully employ much of the statistical information which the Commission has obtained, as so large a proportion of the imports into the United Kingdom for her own use or for her allies, is now employed directly for munitions work. It does not appear in any statistics, and cannot be divulged.

The Commissioners have had discussions with and obtained special information from a number of the British Government Departments, including the Board of Trade, the Ministry of Munitions, the Department of Trade and Commerce of the Board of Trade, the Statistical Department of the Home Office, the Imperial Institute, the London Chamber of Commerce and a considerable number of individuals and firms who are interested in the importation and use of nickel in one or other of the many forms in which it is sent to the United Kingdom. The Official Departments of the United States and of Canada have also published valuable statistics and information as to uses, and their officials have been interviewed in many cases. The publications issued by these bodies and in the United Kingdom and by many of the continental countries, have been carefully examined and made full use of. Among other publications may be mentioned the Annual Statement of the Trade of the United Kingdom with foreign countries, issued by the Department of Trade and Commerce, the United States Reports of Commerce and Navigation, the publications of the United States Geological Survey, and various bulletins which have been issued from time to time by the British Colonies.

Among private individuals and firms who have been interviewed or have supplied information, may be mentioned many large steel makers and users in

[1] J. Soc. Chem. Ind., 1914, 172.

the United Kingdom, France, Norway, Sweden, Canada and the United States, metal brokers in the United States, the United Kingdom and Canada, Professor Thomas Turner of the Metallurgical Department, Birmingham University, Mr. G. A. Boeddicker, of Messrs. Henry Wiggin and Co., Ltd., Messrs. A. D. Keeling and Co., Messrs. W. Canning and Co., all three of Birmingham; also the Mint (Birmingham) Ltd., and a number of important users in Sheffield, whose steel works account for a large proportion of the total consumption of nickel in the British Empire.

The following rough estimates of the annual or relative quantities of nickel used for certain specific purposes have been drawn up from information collected by the Commission during its enquiries or supplied in the form of memoranda. They can only be regarded as approximations, as the estimates supplied by acknowledged experts are stated by them to be more the expression of opinions based on their experience than definite statements.

Coinage:—Not over 500 tons. Nickel for coinage purposes is dealt with more fully later in this Chapter.

Electro-plating:—Metallic nickel and its salts, equivalent to about 500 tons of metallic nickel, is consumed in England.

Nickel Silver and other alloys not containing iron, or that used for coinage, 1,500 to 2,000 tons in England according to one; about 3,000 tons according to another.

Steel Making:—Probably 75 per cent. of the whole present nickel production (war time); and 60 per cent. under normal conditions. In England, about 2,750 long tons is normally used or about 45 per cent. of the whole English consumption, according to one authority who is likely to know but does not wish his name to be given. He states that, in the spring and early summer of 1916, nickel was used at the rate of 4,000 tons per annum for steel making. The Imperial Institute states that 4,700 tons was thus used in 1914, and that it accounted (in England) for about 70 per cent. of the total nickel used.

It may be assumed that the other manufacturing countries—the United States, Germany, France and Austria—employ nickel for its various uses in much the same proportions as does England; but as already stated, no statistics of this kind are available. The great use of nickel is in nickel steel.

As stated above, the principal use of nickel is as metal, mainly for the production of alloys. Pure and what is known as commercially pure nickel is used to an increasing extent in laboratory appliances, and for cooking and table utensils, but is somewhat difficult to work, and the industry prior to the war was almost entirely in the hands of the Austrians. A small amount (under 1 per cent.) of magnesium is commonly added to render the metal more amenable to rolling, spinning, etc., but not enough to justify calling the metal an alloy. For cooking and table use, nickel has many advantages, but its price and the difficulty of working it have prevented its growth, and will probably permanently prevent its use for any purposes where nickel silver and other white alloys such as Monel metal are suitable.

Nickel Steel

The nickel steel industry is dealt with at greater length in another part of the Report. It is practically certain that not less than half the total nickel pro-

duction of the world is used under normal conditions in the manufacture of steel, and of special ferro-alloys such as ferro-nickel, ferro-nickel chrome, and ferro-nickel-tungsten. The special classes of steel which contain nickel are extremely varied, and it is most important to note, that, apart from war requirements, the steels containing it are those in which the greatest development in use is likely to occur, not so much as a great increase in tonnage compared with ordinary steel, but as a very large addition to the present amount used for special nickel steels. Nickel steels and white metals, i.e., non-ferrous alloys containing nickel probably now use up 90 per cent. of the total world production. They were largely and increasingly used before the war and, although war demands are mainly what may be described as temporary, they have emphasized the value of nickel, not only in steel but in cupro-nickel and other alloys, more highly than many years of active advertising propaganda would have done in times of peace. Those who are now using nickel steels in their manufactures for war purposes, or in their tools and machinery for producing the same, now appreciate the value of nickel steel, and will never go back to the use of the ordinary steel with which many of them were formerly satisfied except for very special purposes.

The principal uses for nickel steel are those where increased strength or lightness without sacrifice of strength is required, i.e., where special tensile strength and elongation tests have to be passed. Such, for instance, are trusses and other strain-bearing parts in bridge building, etc., or rails where, as at curves, excessive wear and tear occur, or corrosion is likely to be excessive, or the cost of replacing rails is unusually heavy, as in railway tunnels. It is also largely used for special locomotive forgings, electric railway gears, marine and stationary engine works, and for an enormous variety of parts in automobiles, aeroplanes, etc. It is, in fact, employed for an infinity of purposes, including large castings and forgings such as crank shafts, but particularly the small parts of rapidly moving machinery which must be light but strong and resistant to shock. No special reference need be made to its use for ordnance, except to say that it is employed largely for armour-plate, large and small guns, gun shields and armour-piercing projectiles.

Nickel for making steel is largely sold direct as commercially pure nickel, but sometimes in the form of an alloy with iron, and often with the addition of chromium, tungsten, molybdenum and other metals required in the ultimate composition of the steel. On this account, it is likely that the use of the electric furnace for the smelting of nickel ores and nickeliferous by-products will increase more rapidly in the future than it has done in the past.

Ordinary nickel steels contain under 5 per cent. of nickel and commonly range near 3½ per cent., but highly nickeliferous steels carrying up to 40 per cent. nickel are used for special purposes where non-magnetic qualities, resistance to corrosion and above all, no expansion or contraction, or any desired expansion or contraction, with change of temperature, is important. These steels absolutely control the market for special purposes such as clock pendulums, measuring tapes and certain philosophical instruments, and, although the tonnage is small, it is a rapidly growing outlet for nickel. Such alloys are used in place of platinum as the leading-in wires for electric lamp bulbs, and for many other purposes where a metal having the same coefficient of expansion as another material is required.

Direct Use as Metal

This has already been referred to, but it may be added that a considerable amount of nickel is cast into anodes and used for electro-plating. This, however, probably only amounts to about 2 per cent. of the total nickel produced, and is not likely to very largely increase, because there is a growing tendency to put less nickel on the goods plated, and it should also be remembered that even doubling the consumption for this purpose would be of little importance in the aggregate.

Nickel Alloys other than Steel

An enormous variety of these is in use, mainly of the class known as nickel silver or nickel bronze. They are dealt with in the Chapter on Non-ferrous Nickel Alloys. One important property of nickel in the manufacture of these alloys is its extraordinary power of removing the yellow colour from copper while adding to its strength and other good qualities. The ordinary "nickels" used for coinage contain only 25 per cent. nickel, the remaining 75 per cent being copper. The addition of the nickel to copper, not only completely alters the nature of the copper, but the nickel itself loses its individuality. The alloys of the two metals may be described as true compounds, and the nickel, while robbing the copper of its colour, loses its magnetic properties, so that a nickel coin containing 25 per cent. of nickel or even much more, is absolutely non-magnetic, although pure nickel or cobalt stands next in magnetic properties to iron. Among the non-ferrous nickel alloys may be mentioned other nickel silvers and nickel bronzes, such as cupro-nickel, containing 20 per cent. or less of nickel, and a cupro-nickel alloy containing as much as 50 per cent. of nickel. The general merchant grade of nickel bronze contains about 20 per cent. of nickel. In addition, there are other alloys of great variety and often of considerable complexity. These different alloys, including nickel silver and cupro-nickel, are largely used for table ware, dairy machinery, hardware and plumbing supplies, electrical resistance materials, shells, covers and other parts of cartridges and bullet coatings, etc., and for almost every class of goods where a white metal which can be worked like brass, is suitable.

Monel Metal

Monel metal is fully described in the Chapter on Non-ferrous Nickel Alloys. It is made direct from a roasted matte obtained from the Sudbury ores, without removal of more than a small proportion of the copper, and deserves special mention. It is typical of what are commonly called natural alloys, made from mixed ores or products without first separating the admixed metals in a practically pure state. The latter method is, of course, much more expensive, although it is the common practice on account of the desire of most alloy makers and users to make their own alloys, or at any rate to know that they are made from the "best" materials.

In Monel metal, the International Nickel Company knew that they had a good alloy. They spent large sums in testing it and, having proved its value, in obtaining and even making a market for it. They sold it at so low a price for its nickel contents that purchasers began to buy it in order to treat it electrolytically for the separation of pure nickel and copper, and for the recovery of the precious metals which (being an alloy produced direct from the matte) were present. This

rendered it essential to raise the price sufficiently to prevent such competition. Notwithstanding this, the demand is increasing, and the Commission has seen many evidences of its importance, and has also had unsolicited testimony as to the probable increase in its use where good colour, strength and resistance to corrosion are required. The introduction of Monel metal is of interest as showing how a product made and sold openly as a "natural alloy" can be made popular if deserving, even though it has to compete against the severe trade prejudice which always faces those who adopt unorthodox methods of manufacture. It is specially interesting in connection with the nickel industry for two reasons: (1) as showing the desirability of endeavouring to make "natural" nickel steel direct from nickel ores or from the Sudbury slags, and (2) the competition with the direct use of nickel in steel manufacture, which may be anticipated from an extension of the smelting of the Cuban and other nickeliferous iron ores, which is really a step in the production of natural nickel steel, and which has been dealt with elsewhere in this Report.

Uses of Oxides and Salts

Nickel is largely used in the Edison storage batteries. The oxide is used in the manufacture of glass and for a few other minor purposes, and the salts, such as nickel sulphate and the double sulphate of nickel and ammonium, are largely used in electro-plating. Nickel salts are also employed for what is known as the hydrolysis of fats, i.e., for converting liquid fats into solid fats suitable for soap making and many other purposes for which liquid fat is unsuitable. These and many other uses for nickel oxide and its salts are rapidly growing, but, like the use for coinage, etc., even an enormous percentage increase in the use would add but little to the aggregate consumption. They are dealt with in other parts of the Report, and later, in this Chapter, under Nickel Coinage.

Use as a Catalyst

Hardening Oils:—It has long been known that the oleic acid, which forms the chief constituent of liquid fats and oils, can be converted into stearic acid by the introduction of hydrogen into the molecule, for which purpose the material is heated in presence of a hydrogen carrier in an atmosphere of hydrogen, the carrier acting as a catalyst and itself remaining unchanged. Metals of the platinum group have long been employed for this purpose and about 1896 Sabatier and Senderens[1] found that the same property is possessed by nickel. On the basis of this discovery, numerous processes have been devised, and some of them are now in use on an extensive manufacturing scale, in Germany, England, the United States and Canada. The oil hardening industry is very important and rapidly growing.

Bomer[2] found that hardening raised the melting and solidification points of fats and lowered the refractometer and iodine values, but had little effect on the saponification value. The softer products closely resembled lard in colour and appearance, while the harder products (e.g., from whale oil) could scarcely be dis-

[1] Comptes Rendus., vol. 132, pp. 210, 566 and 1254; Annales de Chim. et de Phys., 1905 (8), Vol 4, pp. 319-488.

[2] Chem. Rev. Fett. Ind., 1912, 19, 218 and 247.

tinguished in appearance, taste, or odour from mutton tallow, and closely resembled lard and tallow in their analytical values. Physiological tests have proved that hardened fats may be used as food, and that no injurious compounds are formed during the hardening process. It is essential, however, that they should be free from nickel and other foreign bodies used in their preparation.

Knapp[1] finds that hardened oils keep very well and show no sign of rancidity after 18 months' exposure to damp air; they give soaps of good colour but deficient in lathering power.

Bedford and Erdman[2] found that all the oxides of nickel are capable of acting as hydrogen carriers for the hydrogenation of oils at atmospheric pressure, and possess the advantage over metallic nickel of being more rapid in action and relatively insensitive to gases containing oxygen and sulphur compounds. With the sesquioxide and monoxide, a temperature of about 250° C. is required, but with nickel suboxide, 180°-200° C. is sufficient. When the higher oxides of nickel are used, they become partially reduced to the suboxide, which forms a colloidal suspension in the oil. Hence a nickel oxide catalyst becomes more active after it has been used, owing to the formation of the suboxide. The activity of nickel oxide is increased by small quantities of the oxides of aluminium, silver, zirconium, titanium, cerium, lanthanum and magnesium. Nickel salts of organic acids do not act as catalysts, but in presence of the heated oil, are decomposed by hydrogen, yielding nickel oxides and metallic nickel which then act as catalysts.

Other compounds of nickel, e.g., the hydroxide, carbonate, borate, formate, etc., have been proposed or employed as catalysts for the hydrogenation of oils; and for each of these compounds, some advantage over metallic nickel, as regards a lowering of the temperature or an increase in the rate of reaction, is claimed. It would appear that the majority of these nickel compounds are not catalysts per se, their catalytic properties being dependent on the degree of reduction effected in them by the action of hydrogen in the presence of heated oil.[3]

The reduction of nickel oxide by hydrogen has been studied by Senderens and Aboulenc,[4] who found the temperature of reduction to depend on the mode of preparation and treatment of the oxide used. Complete reduction is not effected below 300° C., but the mixture of metal and oxide thus obtained is more active catalytically than the metal prepared by total reduction at a higher temperature. Reduced nickel of impaired activity may be restored by oxidizing it and again reducing.

The production of nickel catalysts has formed the subject of many patents, amongst which the following may be mentioned:—

Ellis[5] attaches finely divided electrolytic nickel to a hydrogen-occluding material, such as powdered charcoal, graphite or a catalytically active metal (nickel); the presence of a small amount of zinc, copper, or titanium in the electrolytic nickel increases the absorptive capacity of the latter for hydrogen.

[1] Analyst, 1913, 38, 102.
[2] J. prakt. Chem., 1913, 87, 425.
[3] See Erdmann and Rack, Seifensiederzeit., 1915, 42, 3; Normann and Pungs, Chem. Zeit., 1915, 59, 29 and 41; Erdmann, J. prakt. Chem., 1915. 91, 469; Siegmund and Suida, J. prakt. Chem., 1915, 91, 442; Schonfeld, Z. agnew. Chem,. 1916, 29, 39; etc.
[4] Bull Soc. Chim., 1912, 11, 641.
[5] U. S. Pat. 1, 151,003, Aug. 24, 1915.

According to the same inventor,[1] a finely-divided catalytic material capable of hardening resistant oils, is obtained when nickel hydroxide, with or without copper hydroxide, is incorporated with an oily vehicle and the mass heated in hydrogen, the moisture formed by the reduction being removed.

Bacon and Nicolet[2] impregnate a finely-divided medium with sodium hydroxide and aluminate, and then treat the material with a solution of a nickel salt to obtain a mixture of the precipitated hydroxides of aluminium and nickel, in which the nickel compound is rendered catalytically active by subsequent reduction.

C. and G. Miller, Speisefettfabrik Akt.-Ges.,[3] prepare a nickel catalyst by heating metallic nickel (or its compounds) in the form of shavings, first in hydrogen and then in carbon dioxide, the latter being stated to increase the activity of the product.

The Badische Anilin and Soda Fabrik[4] treats an artificial silicate, such as sodium aluminate silicate ("Permutit") with a nickel salt, and then reduces the latter with hydrogen.

Sulzberger[5] reduces nickel silicate by means of hydrogen or other reducing agent free from anti-catalytic material.

Spieler[6] incorporates gelatinous aluminium hydroxide, gelatinous silica, or a mixture of the two, with a suspension of nickel formate and carbonate in water, then suspends the mass in an oleaginous medium and heats the latter to 235°-250° C. to decompose the nickel salts.

The Bremen-Besigheimer Oelfabriken[7] prepares a nickel catalyst by heating nickel benzoate above 1,000° C. until carbonization of the organic matter and reduction of nickel oxide are effected; or by precipitating nickel carbonate or oxide on fossil meal, mixing the latter with an equal bulk of fine carbon, and heating the mixture above 1,000° C. until pyrophoric. In either case, the product is mixed at once with oil or other indifferent liquid, in which it may be kept indefinitely. It is claimed that fat-hardening with such catalysts can be carried out at 150° — 200° C. and that the carbon present has a deodorizing as well as a bleaching effect.

The first patent for the use of nickel as a catalyst was taken out by J. B. Senderens[8] in 1901, and related to the production of aniline from nitrobenzol; and in the following year, Leprince and Siveke[9] were granted a patent for the hydrogenation of oils. In 1903, Normann[10] took out a patent for the employment of nickel deposited on pumice, as an oil catalyst; and this patent, which was acquired by a large English firm of soapmakers, has been the subject of considerable litigation. In the following years, various methods of applying the catalyst were introduced, among which the following may be mentioned. Bedford and

[1] U. S. Pat. 1,156,068, Oct. 12, 1915.
[2] U. S. Pat. 1,152,591, Sept. 7, 1915.
[3] Eng. Pats. 22,092, Sept. 28, and 23,643, Oct. 16, 1912.
[4] Eng. Pat. 8,462, April 3, 1914.
[5] U. S. Pat. 1,143,332, June 15, 1915.
[6] U. S Pat. 1,139,592, May 18, 1915.
[7] Eng. Pat. 4,023, Mar. 13, 1915.
[8] Ger. Pat. 139,457.
[9] Ger. Pat. 141,029.
[10] Eng. Pat. 1,515.

Williams[1] sprayed the oil in contact with a nickel catalyst in an atmosphere of hydrogen; whilst Schwoerer[2] proposed to atomize the oil with steam in presence of hydrogen and nickelized asbestos. Bedford[3] used nickelized pumice, and Erdmann[4] sprayed the oil into a chamber containing nickel deposited on pumice, etc. Kayser[5] preferred kieselguhr as the nickel carrier, and agitated this with the oil in presence of hydrogen—a method which is said to be largely used in the United States. Bedford and Williams[6] employed nickel oxide (which was previously recommended by Ipatiew), with an operating temperature of about 250° C., in place of 150° — 170° C. for metallic nickel. Shukoff[7] prepared the nickel catalyst by heating nickel carbonyl at 200° C., at which temperature it decomposes, leaving metallic nickel in such a fine state of division that the whole mass becomes black, and the separation of the metal takes a considerable time. Phillips and Bulteel[8], and many others, have proposed to extend the hydrogenation process, with the aid of nickel, to mineral oils, with the object of obtaining products of lower specific gravity than the original material.

Amongst other patented processes for the hardening of oils by means of nickel catalysts, the following may be mentioned:—

Moore's process[9]:—An intimate mixture of the finely-divided oil with hydrogen is passed through the nickel catalyst (supported on a porous diaphragm) in such a way that, while hydrogenation is being effected in one part of the catalyst, other parts of the latter are being freed from hydrogenation products and revivified by a current of hydrogen at high velocity.

In Richardson's process[10], the fat is mixed with nickel which has been electrically disintegrated in an organic liquid, the mixture being hydrogenated and the nickel separated from the product; or nickel oleate is dissolved in the ore to be treated, and the nickel reduced by means of hydrogen; or an electric arc is produced between electrodes of nickel immersed in a volatile solvent for fats (so that part of the metal is finely disintegrated in the liquid), the treated solvent being then added to the oil or fat, and evaporated after treatment of the mixture with hydrogen.

A full description of various other appliances for the hydrogenation of oils by catalytic reduction is given by C. Ellis.[11]

Proposals have also been made to employ nickel catalysts for the synthesis of ammonia from nitrogen and hydrogen, for which purpose F. W. de Jahn[12] reduces nickel oxide with hydrogen, adding metallic sodium, and treating the product with ammonia.

Another catalytic reaction performed by finely divided nickel has been

[1] Eng. Pat. 2520/1907.
[2] U. S. Pat. 902177/1908.
[3] U. S. Pat. 949,954/1910.
[4] Ger. Pat. 211,669/1907.
[5] U. S. Pat. 1,008,474/1911.
[6] U. S. Pat. 1,026,339.
[7] Ger. Pat. 241,823/1910.
[8] Eng. Pat. 23,997/1909.
[9] Eng. Pat. 22,980, Nov. 24, 1914.
[10] U. S. Pats. 1,151,045, Aug. 24, 1915; 1,151,718, Aug. 31, 1915; 1,175,905, Mar. 14, 1916.
[11] "Hydrogenation of Oils," 1915, Constable, London.
[12] U. S. Pat. 1,143,366, June 15, 1915.

described by H. von Beresteyn,[1] who finds that vapours of heptylic alcohol are decomposed, in an atmosphere of hydrogen, by finely divided nickel heated to 220° C. (the most favourable temperature) with formation of normal hexene *a*, carbon monoxide and hydrogen. P. Neogi and B. B. Adhicarz[2] have found that nitric oxide is reduced to ammonia, sulphur dioxide to hydrogen sulphide, and phosphorus pentoxide to hydrogen phosphide by hydrogen in presence of reduced nickel. The reaction begins at about 300° C., and when once started, the temperature can be lowered to 120° C. without stopping it. On passing nitric oxide alone over reduced nickel, no formation of a nitride, nitrite, or nitrate of nickel was observed, and it is concluded that the nitric oxide is reduced directly by the hydrogen, the nickel acting as a catalyser.

Nickel For Utensils

Owing to its general anti-corrosive properties (q.v.) nickel is employed to a considerable extent in the manufacture of cooking utensils, and also of chemical apparatus for laboratory and works use. Not being attacked by fused caustic alkalis or by the vapour of alkali metals, nickel vessels are employed in the manufacture of these materials. For example, the use of a nickel retort is specified in the process of Swan and Kendal[3] for the manufacture of sodium and potassium by distillation.

To save expense, apparatus of large size is frequently made of iron and lined with nickel. In the manufacture of such apparatus, the Chem. Fabr. Griesheim-Elektron[4] interposes an alloy of lead and (or) tin, several millimetres thick, between the iron shell and the nickel lining.

To obtain nickel tubes, plates and other utensils electrolytically in thick and sound layers of metal, Levi[5] deposits the nickel from an acid aqueous solution of nickel sulphate, preferably hot, and obtains uniform density in the deposits either by circulating or agitating the electrolyte, or by moving or rolling the objects in the bath. By employing a hollow mandrel of aluminium or other metal, and supporting this on a stretched wire or cable on which the mandrel turns during the electrolysis, the nickel is deposited in the form of long tubes from which the aluminium is afterwards removed by solution or fusion. One or more layers of metals, either cheaper than or possessing properties different from the nickel may also be deposited between layers of nickel by this process.

It has also been proposed to employ nickel oxide as a protective coating for utensils of mild steel for which purpose Haefner[6] employs a mixture of the oxides of nickel, copper, cobalt, and manganese (dioxide) with or without oxide of iron.

Use In Electroplating

The fact that a bright electro-deposit of nickel can be produced on other metals was first recorded by Boettger in 1843; but, in consequence of the high price of the metal and the difficulty of obtaining it in a sufficiently pure state, nickel-

[1] Bull. Soc. Chim. Belg., 1911, 35, 293-300.
[2] Z. anorg Chem, 1910, 69, 209-214.
[3] Eng. Pat. 25,100, Oct. 28, 1910.
[4] Eng Pat. 25,957, and Fr Pat. 422,985, of 1910.
[5] Fr. Pat. 436,380, Jan 20, 1911.
[6] Ger. Pat. 282,114, Apr. 10, 1913, addition to Ger. Pat 257,299.

plating, as an industry, was only begun about 1870. Since 1875, however, it has developed to a phenomenal extent for producing a non-tarnishing, silver-like coating on numerous articles, such as machine parts that are not exposed to friction, sewing machines, cycles, pencil cases, umbrella fittings, coffee urns, cutlery, etc., and other iron and steel goods, as well as on brass and zinc articles, and latterly on aluminium.

Electrolytically deposited nickel is hard, and initially dull, but will take a brilliant polish if the underlying surface is very smooth; and it affords a good protection to metals that are more susceptible than itself to atmospheric and other influences. The surface to be coated must be quite free from grease or tarnish; these being removed, if necessary, by dipping in an acid or cyanide bath. Articles of copper and brass can be coated direct, but those of iron or zinc have first to be coated with copper; and in the case of goods which are to be replated, the old deposit must be removed by a mixture of dilute nitric and sulphuric acids, or at least deoxidized by means of hydrogen in an acid electrolyte.

The plating solution generally consists of nickel-ammonium sulphate, in the proportion of about 1 lb. per gallon, with or without an addition of nickel sulphate, the conductivity of the solution being improved by the use of a little potassium chloride, boric acid, etc. Nickel sulphate, being more soluble than the above double sulphate, is sometimes used alone, in which case a conducting salt (alkali- or alkaline-earth sulphates or chlorides) is essential. The bath should be slightly acid. The current employed is one of about 5 volts, until the cathode (article) is completely covered with deposit, whereupon it is reduced to 3 volts, the current density being about 5 amperes per sq. foot (rather higher when nickel sulphate is used).

Full particulars of the details of nickel plating, including the questions of anodes, management of the bath, electrical conditions, special treatment of the articles to be plated, stripping old deposits, etc., will be found in the special textbooks on the subject, such as "Electroplating," by Barclay and Hainsworth, London, 1912, Arnold; "Electrometallurgy," by McMillan and Cooper, London, 1910, Griffin & Co.

Some of the more recent processes are given below:

According to C. W. Bennett, H. C. Kenny and R. P. Dugliss,[1] the best deposits of nickel are obtained when a definite quantity of ammonia is added to the solution of nickel ammonium sulphate, the efficiency being dependent upon the degree of alkalinity of the cathode film, and if the solution is vigorously stirred, being diminished. It is considered probable that, in acid solutions, nickel is deposited only when the impoverishment of the hydrogen ions causes the solution to become alkaline. The iron content of the anode does not materially affect the efficiency, but, with a rotating cathode, the iron content of the deposit is greater than that formed on a stationary one, probably because the protective ammoniacal film is removed.

P. Marino[2] prepares the plating bath by treating a solution of a nickel salt with a reagent, such as sodium phosphate or potassium chromate, and then com-

[1] Trans. Amer. Electrochem. Soc., 1914, 25, 335-346.
[2] Eng. Pat. 9,957, July 8, 1915.

pletely dissolving the precipitate in a solvent, such as phosphoric acid or potassium cyanide. Ammonium, sodium, or potassium salicylate and ammonia are added to the solution thus prepared.

In another process by the same inventor,[1] a sheet of the metal ar alloy to be deposited is used as anode in an electrolyte composed of a concentrated solution of sodium pyrophosphate containing about 10 per cent. of phosphoric acid and 5-15 per cent. of sulphanilic acid. When the electrolyte is saturated, the metal is deposited in the metallic state on the surface of the cathode.

Black coatings of nickel have been obtained by E. Werner,[2] in bath consisting, for example, of: H_2O 100 litres, $(NH_4)_2SO_4$, $NiSO_4$, $6H_2O$ 8505 grms., KCNS 2125, $CuCO_3$, $Cu(OH)_2$ 1417, and H_3AsO_3 1417 grms. Among the conditions to be observed are: maximum density of bath, which must be neutral; large, old anodes; potential difference not exceeding 1 volt; regular working; thin plating, as shown by attainment of a deep black, to avoid scaling.

A. Leuchter[3] employs a nickel anode for the simultaneous deposition of nickel and iron upon a conducting surface, a preponderance of iron being maintained in the electrolyte, and the electromotive force of the current being reduced, by the rheostatic effect of the anode, to a value intermediate to those required for the deposition of nickel or iron alone.

In another process by the same inventor,[4] the anode is composed of nickel alloyed with 2 to 7 per cent. of manganese, and the electrolyte contains nickel-ammonium and manganese-ammonium sulphates in such quantities that the relative proportions of nickel and manganese in the solution are 75—85 and 25—15, respectively.

In a process for electrodepositing nickel in great thicknesses, A. Hollard[5] eliminates hydrogen (which causes exfoliation of the deposit) by using a compound that gives up hydrogen to the current with difficulty. It is stated that nickel fluoborate gives excellent results with a current of 1 amp. for electrodes 14 x 18 cm.; and that by this means, nickel may be deposited direct on cast iron and aluminium.

Difficulty has been experienced in electro-plating aluminium with nickel, owing to the deposit lacking coherence; and an intermediate coating has generally been considered indispensable, for which purpose copper, zinc and iron have been proposed and tried in various ways. In any case, a chemically clean surface must be secured on the aluminium, and to the well-known difficulty of obtaining this must be attributed failure to secure a deposit which will stand mechanical working. Canac and Tassily[6] claim to have overcome this defect in the following way: The aluminium piece to be plated is passed first through a boiling potash bath, then brushed with milk of lime, dipped in a 0.2 per cent. potassium cyanide bath for several minutes, and finally subjected to attack by an iron chloride solution (500 gm. hydrochloric acid, 500 gm. water, 1 gm. iron), till the appearance of the

[1] Eng. Pat. 10,133, July 12, 1915.
[2] Elektrochem. Zeits., 1913, 20, 25-26.
[3] U. S. Pat. 1,026,627, May 14, 1912; Eng. Pat. 9075/12.
[4] U. S. Pat. 1,026,628, May 14, 1912.
[5] Chem. News, V. 107, p. 294.
[6] Comptes Rendus, 1914, V. 158, p. 119.

aluminium resembles crystallized tin plate. After each stage in this treatment the work is thoroughly washed in water. The following is found to be a satisfactory nickeling solution: Water, 1,000 cc.; nickel chloride, 50 gm.; boric acid, 20 gm., worked at 2.5 volts and 1 ampere per sq. dcm. The deposit obtained is matte-grey on leaving the bath, but takes a good polish, and will stand bending and hammering without peeling or cracking. The reason for the adherence of the deposit appears to lie in the strong reducing action of the nascent hydrogen evolved when the aluminium is plunged in the ferrous chloride pickle. Metallic iron is deposited on the aluminum, and, though its amount is so small (0.25 to 0.5 gm. per sq. metre) that it cannot form a continuous intermediate deposit, the iron forms with the aluminium, a number of tiny couples favouring attack by the acid pickle. The surface of the aluminium is thus very minutely but very completely pitted so that, besides being deposited on the nearest practicable approach to a chemically pure surface, the nickel coating is actually locked or "rooted" into every part of the aluminium surface, and it is on this mechanical action that the tenacity of the deposit depends. (This feature has been confirmed by E. Tassily—Rev. Met. 1914, Vol. II, p. 670.) Aluminium thus protected, is said to be unaffected by moist air, dilute and boiling soda, acetic acid, sea salt, wines and foodstuffs, and does not permit leakage of petrol. It is recommended as useful for electrical conductors, and is claimed to extend greatly the possible applications of aluminium.

The direct nickel-plating of aluminium has also formed the subject of several patents. Thus, in the process of M. Chirade and J. Canac,[1] the aluminium is immersed successively in tepid water and a 2 per cent. solution of potassium cyanide, after which it is washed and placed in a scouring bath composed of hydrochloric acid (1 : 1) containing 0.1 per cent. of iron chloride. It is then washed and treated for five minutes in a nickel plating bath, a current of 3 volts being employed, and finally washed with boiling water.

In an addition dated Sept. 16, 1912, to the preceding French patent, the articles are first cleansed with potash and milk of lime, then immersed in a bath of potassium cyanide, and afterwards passed through a bath containing metallic iron and hydrochloric acid. They are finally introduced into the plating bath containing nickel chloride and boric acid, the successive operations being in each case separated by a prolonged washing with cold water.

In the process of L'Aluminium Francaise,[2] the article to be coated is immersed in a solution of a nickel salt to which has been added ammonium or other alkali or metallic phosphites or hypophosphites, the solution being heated to increase the speed of deposition. This process is also applicable to the nickeling of glass or porcelain.

In Marino's process[3] for decorating pottery and glassware with metallic nickel, the surface of the article is first metallized and rendered electrically conductive —by successively coating with silver fluoride, treating with coal gas, and heating to about 50° C. in the vapour of carbon bisulphide—and then electroplated with nickel.

[1] Eng. Pat. 24,019, Oct. 30, 1911; Fr. Pat. 446,949/1911.
[2] Fr. Pat. 464,721, Jan. 20, 1913.
[3] Eng. Pat. 14,033, June 13, 1911.

For Anodes of Storage Batteries

Nickel, in the form of oxide or hydroxide, has been proposed for the anodes of electric storage batteries.

For example, T. A. Edison[1] has made a depolarizing electrode for storage batteries by powdering nickel hydroxide and a substance containing bismuth in such proportions that the mixture contains 20 per cent., or less, of the bismuth material. A perforated non-deformable enclosing pocket is loaded under pressure with the mixture.

In a second patent, Edison[2] precipitates nickel hydroxide by mixing a solution of a nickel salt and an excess of alkali hydroxide; the precipitate, together with the excess of alkali and some or all of the soluble reaction product, being evaporated to a creamy consistency, and the mixture then slowly dried. The excess of alkali and the soluble reaction product are removed by washing and the residue dried.

H. C. Hubbell[3] makes storage-battery electrodes by arranging alternate layers of cobalt, nickel and a metal having a solubility similar to copper in the order:—copper-like metal, cobalt, nickel, cobalt, and copper-like metal. The copper layers are dissolved by using the plate as anode in a solution containing sodium and ammonium acetates and free ammonia, at a current density which leaves the cobalt unattacked, then oxidizing the latter by employing the plate as anode in a dilute solution of phenol and fixed alkali, using a "forming" current of low density.

According to another process by the same inventor,[4] electro-deposited layers of different metals, e.g., nickel and a more soluble metal such as copper, are arranged alternately to form bars, which are united into a plate with the layers disposed edgewise to the faces of the plate. The copper is dissolved away by using the plate as an anode in a solution of sodium and ammonium acetates containing free ammonia, at a current density sufficiently low to leave the nickel unattacked, and the nickel is finally oxidized by using it as anode in a dilute solution of phenol and fixed alkali, employing a "forming" current of low density.

Nickel oxide plates for secondary batteries are made by P. Hoyer,[5] by moistening a granular mass of nickel (obtained, for example, by igniting nickel carbonate in a reducing atmosphere) and applying it to a support of perforated sheet nickel or nickel wire gauze. After drying, the plate is heated to redness in a reducing atmosphere, then used as anode in the electrolysis of a solution of sodium or potassium carbonate, and the nickel subsequently oxidized electrolytically in a concentrated solution of potassium or sodium hydroxide.

According to the Svenska Ackumulator Aktiebolaget Jungner,[6] the activity of nickel oxide electrodes in alkaline accumulators may be restored by withdrawing the electrolyte and adding a hot solution of sugar, or other suitable reducing agent, for several hours.

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[1] U. S. Pat. 1,036,471, Aug. 20, 1912.
[2] U S. Pat. 1,167,484, Jan. 11, 1916.
[3] U. S. Pat. 1,087,236.
[4] U S Pat. 1,175,954, Mar. 21, 1916.
[5] Ger. Pat. 277,743, July 17, 1913.
[6] Fr. Pat. 466,543, Dec. 24, 1913. Conv., Jan 16, 1913; Eng. Pat. 72 of 1914.

The same firm has patented a process[1] for making electrodes from the higher oxides of nickel by reducing a mass composed of these oxides to a lower state of oxidation by the aid of a reducing liquid or gas.

In this connection, C. Russo[2] has investigated the velocity of solution and polarization of nickel anodes in sulphuric acid, and has found that the passive state is attained with a current of 0.1 ampere, beyond which the velocity of solution diminishes until the current density reaches 0.4 ampere, after which an increase is recorded.

For Colouring Ceramic Ware

For colouring ceramic ware, nickel oxide is employed both for in-glaze and underglaze decoration, and in the former case furnishes light blues and greens to dark olive green, according to the metallic oxides with which it is associated. Thus, with zinc oxide, blues are obtained; with magnesia, green; and with alkalis and alkaline-earths, brown shades. The colours also vary with the glaze and the quantity of nickel oxide used. Owing to the tendency of nickel oxide to dissolve in glazes and turn brown, its use as an underglaze pigment is not recommended where other shades are desired. According to Hainbach,[3] nickel is used for producing lustre effects on pottery, and gives an agreeable light brown lustre when fired. Various processes for decorating pottery and glassware with metallic nickel have been patented; examples are given under "Electroplating."

Miscellaneous Uses

The use of nickel hydroxide as a reagent in tannin estimation is recommended by Singh,[4] who also suggests the possibility of manufacturing pure tannic acid from tannin compounds of nickel; of tanning leather by means of tannin compounds of nickel; and of decolourising and concentrating tannin extracts by means of nickel hydroxide.

Production of Alkali Hydroxides:—In a process for manufacturing sodium or potassium hydroxide, with simultaneous recovery of by-products, Braunschild and Chapiro[5] heat sodium or potassium compounds, scuh as carbonates, with oxides of nickel (preferably the higher oxide), and the alkali oxide or hydroxide formed is separated by solution in water, any gaseous product (carbon dioxide, etc.) being recovered. The lower oxides of nickel remaining as residue are then used again, with or without previous re-oxidation by roasting.

Nickel Coinage

Although the so-called nickel coinage appears to have first been regularly used in Belgium in 1861, when coins of 5, 10, and 20-centimes of nickel-bronze, commonly called nickel or nickel silver, were introduced, one-cent coins of nickel bronze were authorized in the United States under an Act dated February 21st, 1857, and were issued until the Act was repealed, April 22nd, 1864. They weighed 72 grains and were made of an alloy of 12 per cent. nickel and 88 per cent.

[1] Eng. Pat. 1062, Jan. 14, 1914; Fr. Pat. 467,311 of 1914.
[2] Gaz. Chim. Ital., 1910, p. 491.
[3] "Pottery Decorating," 1907, London; Scott, Greenwood & Son, p. 207.
[4] J. Soc. Chem. Ind., 1911, 936.
[5] Fr. Pat. 431,232, Sept. 5, 1910.

copper. By the Act of April 3rd, 1865, three-cent pieces weighing 30 grains and composed of the alloy now most commonly used for nickel coinage (25 per cent. nickel and 75 per cent. copper) were authorized, followed, under the Act of May 16th, 1866, by 5-cent pieces made of the same alloy and weighing 77.16 grains. It is stated, in the History of the United States Mint, 1885, page 22, that the nickel came chiefly from Lancaster county, Pa., and the copper from the mines of Lake Superior.

The history and development of nickel coinage is very fully dealt with in the Annual Reports of the Royal Mint, London, by Sir Edward Rigg, C. B., Superintendent of the Operative Department, and information has been received from him and from the Mint, Birmingham, and others by the Commissioners, who have also inspected collections, including that of the Mond Nickel Company, showing the extent to which the use of nickel coinage has grown. The Commission is also indebted to Dr. James Bonar and Mr. A. H. W. Cleave, of the Mint at Ottawa, for notes regarding the manufacture of nickel and of nickel-bronze coins, and to a number of extremely full reports, etc., issued by the French Mint.[1]

Pure nickel coins are hard and of fine colour, but the metal is less easy to mint than the cheaper alloy of 25 per cent. nickel and 75 per cent. copper, which is commonly used and which wears at least as well as the bronze—so-called "copper" —coins.

True nickel coins can be easily identified by means of a magnet. They are readily attracted by a hand magnet such as a magnetized pocketknife blade whereas the ordinary "nickel" (made of the 25:75 per cent. alloy) or other nickel-copper alloys, are entirely unaffected even by a powerful electro-magnet.

Sir Thomas K. Rose (42nd Annual Report, Royal Mint, London, pages 107-112) states that the harder the coin, the less wear occurs in use, that the coins are rendered harder outside by stamping, and that the best wearing qualities may be anticipated from thin coins struck in the heaviest presses.

According to Mr. A. H. W. Cleave, 3,000,000 five-cent pieces, would require:—

		Nickel, lbs.
If of pure nickel	about	35,500
If of 25 per cent. nickel and 75 per cent. copper	about	8,375

It would appear that the total weight of metallic nickel used in coinage to date either as pure nickel or the ordinary nickel-copper alloy, has amounted to between 10,000 and 15,000 tons, and that the present annual consumption for

[1] *Projet de Loi* portant retrait des monnaies de billon en circulation et leur remplacement par des monnaies de nickel perforées (Renvoyé à la Commission du budget) Présenté Au nom de M. Armand Fallières, Président de la Republique Francaise, Par M. L.-L. Klotz, Ministre des Finances. (17 pages) No. 1976 Chambre des Députés, Dixième Législature, Session de 1912. Annexe au procès-verbal de la 2° séance du 11 juin, 1912.

Rapport fait au nom de la Commission du Budget Chargée D'Examiner Le Projet De Loi portant retrait des monnaies de billon en circulation et leur remplacement par des monnaies de nickel perforées par M. Adrien Veber, Député. (63 pages) No. 2360, Chambre des Députés, Dixième Legislature, Session Extraordinaire de 1912, Annexe au procès-verbal de la 2° séance du 10 décembre, 1912.

"Journal Officiel de la République Francaise," December 21st, 1912, and August 6th and 7th, 1913.

coinage is not over 500 tons. This figure will probably be immediately and largely increased on account of the enhanced demand for coins of low denomination, and the growing preference for nickel and nickel-bronze for the purpose. It is stated that the French mint will be stamping 5,000 kilogrammes of nickel weekly, of 25, 10, and 5-centime pieces from September, 1916, and that during the current year (1917) over £160,000 worth of nickel and bronze coins will be struck there. This weight is equivalent to over 250 tons of metallic nickel per annum, as the coins referred to will apparently be of pure nickel and not of nickel-bronze.

Growth of Nickel Coinage

The following particulars regarding the employment of nickel and nickel-bronze coinage are quoted from Sir Edward Rigg (42nd, 44th, and 45th Annual Reports of the Deputy Master and Comptroller of the Mint, London, for 1911, 1913 and 1914 respectively), with additions supplied by him for this report, in 1916. Sir Edward says in the 42nd report, pp. 42 and 43:—

Until 1906, the only coins of this alloy struck were for Jamaica, but the Orders-in-Council dealing with the currency of West Africa and of East Africa and Uganda, and subsequent orders relating to Ceylon and British Honduras, directed that several coins of this nickel alloy should be struck for those Colonies. The numbers of pieces struck in the Mint for them annually have been:—

In 1907	1,862,848	pieces.
1908	12,817,152	"
1909	33,670,000	"
1910	18,744,509	"
1911	15,215,491	"
1912	38,258,000	"
1913	16,305,600	"
1914	38,597,600	"

Many of the pieces were struck under contract, in years subsequent to 1910. The use of nickel in currency has thus become a question of special interest to the Mint, and, in dealing with it, frequent difficulty has arisen owing to the common practice of using the term "nickel" in official and other documents indifferently when referring to coinages of pure nickel or of the alloy, which contains only 25 per cent. of that metal. I have therefore been at some pains to ascertain the nature of the metal employed in the countries of the world which possess such a currency, and have collected in tabular form these details as well as the numbers of coins of each denomination issued to the close of 1910, giving also the period during which the currency has been issued. These returns, brought down to the end of 1914, are recorded in the table which follows, and they are of considerable interest.

Dealing with the coins of pure nickel, it will be seen that, of the net issues—941,449,020 pieces—no less than 560,604,758 are current in Austria-Hungary, and, as a rule, the metal is only employed in other countries for coins of relatively high value, that is 2d. or more.

Nickel appears to have been first regularly used in Belgium in 1861, when coins of 20, 10 and 5-centimes in the alloyed metal were issued. No British colony employs pure nickel, and the returns show that 467,293,120 nickel-bronze coins were issued in the British Empire from their first introduction (in Jamaica in 1869) to the end of 1914. Comparing the net issues of nickel and nickel-bronze coins, it will be seen that the number of the latter is more than five times as great as that of the former.

The table given below, showing the countries which have adopted nickel as a coinage metal, with the date of its introduction, is from Sir Edward's contribution to the 44th Mint Report, p. 94.

Introduction of Nickel Currencies

Year.	Countries.	Remarks.
1857	United States	12 per cent. nickel introduced but abandoned.
1861	Belgium	
1866	United States	Definitive adoption.
1869	Jamaica	20 per cent. alloy until 1906.
1873	Germany	
1874	Colombia	
1883	Bolivia	
1884	Ecuador, Servia	
1886	Egypt	
1887	Switzerland	First legalized, 7th May, 1850.
1888	Bulgaria, San Domingo	
1889	Japan, San Salvador	
1890	Brazil	
1892	Austria-Hungary	Pure nickel.
1893	Greece	
1897	Hayti, Martinique	
1898	Siam	Nickel-bronze.
1899	Argentina	Legalized December, 1896.
1900	Crete, Guatemala, Persia, Portugal	Legalized in Portugal 21st July, 1889.
1901	Luxemburg, Uruguay	
1902	Italy, Korea	25 per cent. alloy legalized in Italy 21st February, 1894. Replaced by pure nickel 7th July, 1901.
1903	British North Borneo, France, Guadaloupe, Paraguay, Philippines	
1904	Costa Rica	Legalized 14th August, 1900.
1905	Danish West Indies, Roumania	Legalized in Roumania 5th April, 1900.
1906	Congo State, East Africa and Uganda, Mexico, Montenegro, Reunion	Introduced in Mexico in 1881, but abandoned.
1907	British Honduras, Holland, Nigeria, Panama.	Legalized for Reunion, 1896.
1908	German East Africa, India, Zanzibar, Germany and Siam (for pure nickel)	Legalized in India 2nd March, 1906.
1909	Ceylon, Kiao Chau	
1911	Turkey	Legalized 14th March, 1911.
1912	Nicaragua	Legalized 1912

The following table shows what would be the weight and cost of nickel and nickel-bronze coins identical in dimensions with 1s., 6d. and 3d. English coins of silver.

Weight and Cost of Nickel and Nickel-Bronze Coins

WEIGHTS

English Silver.		Corresponding weight in	
Denomination.	Weight.	Pure Nickel.	Nickel-Bronze.
	grs.	grs.	grs.
Shilling	87.27	73.5	75.0
Sixpence	43.64	36.75	37.5
Threepence	21.82	18.375	18.75

COST OF METAL

Dimensions of Pieces	Pure Nickel			Nickel-bronze alloy.		
	Pieces per ton.	1,000,000 Pieces.		Pieces per ton.	1,000,000 Pieces.	
		Weight.	Cost.		Weight.	Cost.
		Tons.	£		Tons.	£
Shilling	213,333	4.688	802	209,066	4.783	453.3
Sixpence	426,666	2.344	401	418,133	2.3915	226.6
Threepence	853,333	1.172	200.5	836,266	1.1957	113.3

The prices are those paid by the Royal Mint: nickel, £171, and copper, £69 7s. 6d. per ton (2,240 lbs.)

The table below is compiled from Sir Edward Rigg's reports for 1911, 1913 and 1914. It shows the nickel and nickel-bronze coinages of the world to the end of 1914, with their denominations and the periods during which they were struck.

Nickel and Nickel-Bronze Coinages of the World

Country and Period.	Denomination.	Pure Nickel.	25 p.c. Nickel and 75 p.c. Copper.
Argentina (a), 1899-1914	20 centavos	....	21,183,365
	10 "	....	31,611,924
	5 "	....	26,506,742
Austria-Hungary, 1892-1914	20 hellers	240,270,049	....
	10 "	320,334,709	....
Belgium (b), 1861-1910	25 centimes	....	16,043,690
	20 "	....	1,803,670
	10 "	....	154,628,830
	5 "	....	140,398,483
Bolivia, 1883-1909	10 centavos	....	34,800,100
	5 "	....	21,200,080
Brazil, 1890-1902	400 reis	....	19,687,088
	200 "	....	49,455,582
	100 "	....	63,213,548
British Honduras, 1907-12	5 cents	....	50,000
British North Borneo, 1903-4	5 "	....	1,000,000
	2½ "	....	2,000,000
	1 cent	....	2,000,000
British West Africa, 1907-14	Pence	....	15,936,000
	Halfpence	....	12,264,000
	1/10th penny	....	66,600,000
Bulgaria, 1888-1907	20 stotinki	....	20,000,035
	10 "	....	28,194,535
	5 "	....	48,850,035
	2½ "	....	12,000,000
Ceylon (c), 1909-12	5 cents	....	10,000,000
Colombia, 1874-1914	10 "	....	133,700
	5 "	....	39,564,504
	2½ "	....	4,000,000
	2 "	....	11,456,342
	1¼ "	....	2,400,000
	1 cent	....	31,808,161
Congo State, 1906-12	20 centimes	....	3,050,000
	10 "	....	12,400,000
	5 "	....	13,700,000
Costa Rica, 1904	2 centimos	....	630,000
Crete, 1900	20 lepta	....	1,250,000
	10 "	....	2,000,000
	5 "	....	4,000,000
Danish West Indies, 1905-13	5 cents or 25 bits	199,161	60,000,000
East Africa and Uganda (d), 1907-12	10 cents	....	3,850,000
	5 "	....	1,540,000
	1 cent	....	89,029,200
	½ "	....	900,000
Ecuador, 1884-1909	5 centavos	....	3,200,000
	2 "	....	2,500,000
	1 "	....	4,500,000
	½ "	....	5,000,000
Egypt, 1886-1914	10 ochr-el-guerche	....	12,001,383
	5 "	....	66,474,338
	2 "	....	18,213,774
	1 "	....	40,267,686
France, 1903-14	25 centimes	40,941,133	....
	10 "	3,972	....

Nickel and Nickel-Bronze Coinages of the World—Continued

Country and Period.	Denomination.	Pure Nickel.	25 p c. Nickel and 75 p c. Copper.
Germany (e), 1873-1914	25 pfennige	30,001,796	....
	20 "	....	25,029,304
	10 "	....	794,688,261
	5 "	....	768,065,497
German East Africa, 1908-12	10 hellers	....	1,012,363
	5 "	....	2,000,314
Greece, 1893-1914	20 lepta	....	18,790,735
	10 "	....	32,884,038
	5 "	....	30,923,196
Guadaloupe, 1903	1 franc	....	700,000
	50 centimes	....	600,000
Guatemala, 1900-12	1 real	....	26,000,000
	½ "	....	12,000,000
	¼ "	....	8,000,000
Hayti, 1897-1907	50 cents	....	2,000,000
	20 "	....	5,000,000
	5 "	....	30,000,000
	2½ "	....	4,000,000
Holland, 1907-14	5 "	....	21,800,000
India (f), 1908-12	1 anna	....	254,327,920
Italy (g), 1902-14	25 centesimi	13,668,000	....
	20 "	105,229,666	100,000,000
Jamaica (h), 1869-1912	Pence	....	1,704,000
	Halfpence	....	3,864,000
	Farthings	....	4,128,000
Japan, 1889-1906	5 sen	....	183,811,420
Kiao-Chau, 1909-12	10 cents	....	449,829
	5 "	....	621,478
Korea (j), 1902-10	5 cash	....	139,848.319
	1/20th yen	....	109,150
	5 chon	....	40,006,160
Luxemburg, 1901-8	10 centimes	....	4,000,000
	5 "	....	3,500,000
Martinique, 1897	1 franc	....	300,000
	50 centimes	....	600,000
Mexico, 1906-14	5 cents	34,793,885	....
Montenegro, 1906-14	20 paras	1,800.156	....
	10 "	1,800,156	....
Nicaragua, 1914	5 centavos	....	760,000
Panama, 1907	2½ cents	....	800,000
	1 cent	....	1,000,000
Paraguay, 1903	20 cents	....	1,750,005
	10 "	....	2,000,005
	5 "	....	1,000,005
Persia, 1900-14	2 shahis	....	35,000,000
	1 "	....	46,000,000
Philippine Islands, 1903-8	5 centavos	....	10,000,384
Portugal, 1900	100 reis	....	16,000,000
	50 "	....	8,000,000
Reunion, 1906	1 franc	....	500.000
	50 centimes	....	1,000,000
Roumania, 1905-7	20 bani	....	8,000,000
	10 "	....	52,000,000
	5 "	....	74,000.000
San Domingo, 1888-97	2½ centavos	....	4,950,000
	1¼ "	....	500,000
San Salvador, 1889	3 "	....	333,333
	1 "	....	400 000
Servia, 1884-1904	20 paras	....	11.650.035
	10 "	....	14.700.032
	5 "	....	21.000,088

Nickel and Nickel-Bronze Coinages of the World—Continued

Country and Period.	Denomination.	Pure Nickel.	25 p.c. Nickel and 75 p.c. Copper.
Siam (l), 1898-1914	20 satangs	....	3,126,300
	10 "	16,500,000	3,810,178
	5 cents	21,000,000	5,080,238
	10 "	....	5,080,238
Switzerland, 1887-1914	5 "	32,500,000	....
	2½ "	....	43,500,000
	20 centimes	....	72,000,000
Turkey, 1913-14	10 "	9,248,943	....
	5 "	24,350,594	....
	40 paras	31,795,328	....
	20 "	30,579,472	....
United States (m), 1866-1914	5 "	....	891,743,975
	5 centesimos	....	31,378,316
Uruguay, 1901-10	2 "	....	11,000,601
	3 "	....	17,504,262
	1 "	....	10,001,350
Venezuela, 1880-1914	10 centavos	....	4,000,000
	5 "	....	4,000,000
Zanzibar, 1908	20 cents	100,000	....
Total issues		955,117,020	5,167,630,124
Demonetised and withdrawn		13,668,000	406,748,223
Net issues		941,449,020	4,760,881,901

NOTES TO TABLE

(a) A law passed by the Argentine Legislature in 1879 authorized the issue of five-cent and two-cent coins containing 15 per cent. nickel and 85 per cent. copper, but no such coins appear to have been issued. The coins here recorded are issued under the law of 1881.

(b) Since 1904, the Belgian coins of nickel-bronze have been perforated. The following coins of earlier issues have been withdrawn:—

20 cents	1,803,670	Total, 141,870,600 pieces.
10 "	75,360,736	
5 "	64,706,194	

(c) Square coins with rounded corners.

(d) These coins are perforated.

(e) The 20-pfennige pieces, numbering 25,029,304, were demonetised in 1900 and subsequently withdrawn.

(f) These coins are scolloped on the edge.

(g) The Italian coins of pure nickel (25 centesimi, 13,668,000 pieces) and of nickel-bronze (20 centesimi, 100,000,000 pieces) are in course of withdrawal. Their numbers are given above.

(h) The Jamaica coins struck between 1869 and 1906 contained 20 per cent. nickel and 80 per cent. copper. Their numbers were:—

Pence	1,284,000	Total, 7,812,000 pieces.
Halfpence	2,976,000	
Farthings	3,552,000	

(j) The 139,848,319 Korean coins of 5-cash have been demonetised and are in course of withdrawal.

(k) These coins are perforated.

(l) The nickel-bronze coins of 10 and 5-satangs are now in course of withdrawal.

(m) Under an Act of 21st Feb., 1857, nickel-bronze cents (containing 12 per cent. nickel and 88 per cent. copper) were issued in the United States concurrently with those of copper. Their number is not known, and the issue was discontinued in 1864.

Nickel-Silver-Zinc Alloy for Coins

The London *Times* trade supplement for 7th February, 1917, gives the text of a bill drafted for the decimalization of the British coinage. It will be submitted to the various Chambers of Commerce, and amended if necessary before introduction to Parliament, and is of interest, as for the first time true nickel-silver coins are suggested in addition to the ordinary gold, silver and bronze coins, which will remain unaltered. The new coins will be respectively one-tenth and one-twentieth of the English florin, which itself is one-tenth of the standard English sovereign. It is proposed that these coins should be scalloped, and should be called respectively the British dime of ten cents, and the half-dime of five cents, the British cent being one-hundredth of a florin, or roughly half an American cent. The composition for the new "nickel" coins will be nickel 22.5 per cent., silver 60 per cent., and zinc 17.5 per cent.

Cobalt Coinage

The use of cobalt coinage has been suggested in the Twenty-fourth Annual Report of the Ontario Bureau of Mines, 1915 (page 23):—

> It may be permissible to point out that a still further avenue is open for the employment of cobalt. The 5-cent piece is the least desirable of our Canadian silver coins, mainly because of its smallness in size and the consequent difficulty in handling it, and especially of distinguishing it from the 10-cent piece without ocular examination. Why should it not be replaced by a coin made of pure cobalt, intermediate in size between the 10-cent piece and the 25-cent piece? Such a coin would have many advantages. It would be readily distinguishable from all other coins. It would be attractive in colour, pure cobalt being similar in appearance to pure nickel, but somewhat more silvery, and tarnishing slowly, if at all. Being very hard, it would be difficult to counterfeit. Lastly, the chief source of cobalt being for the present in Canada, a cobalt coin would be distinctively Canadian, and its introduction would strike a chord to which the national consciousness would readily respond. The coin could be called a "cobalt," just as the U. S. 5-cent piece of copper-nickel alloy is called a "nickel." By comparison, however, a pure cobalt coin would be greatly superior in appearance and every other respect to the so-called "nickel," which contains only 25 per cent. of that metal.

CHAPTER VI

Non-Ferrous Nickel Alloys

Introduction

The alloys of nickel with metals other than iron are of special interest in connection with the development of the nickel industry, since its early growth was directly due to them. Although the quantity of nickel required is now small in comparison with that for steelmaking, probably less than one quarter, the variety of the non-ferrous alloys, and the fact that they are essential for many purposes, renders them of equal, if not greater, relative importance, except in the matter of tonnage of nickel consumed, even than nickel steels. The consumption of nickel in its alloys, i.e., in steels and non-ferrous alloys, accounts for between 80 and 90 per cent. of the total world's production of the metal.

As will be seen from the description of the individual alloys into whose composition nickel enters, it possesses special powers of hardening and toughening other metals and alloys, and of increasing their strength and resistance to corrosion. In many cases, it improves the grain and general soundness and homogeneity of the alloy, and its extraordinary property of whitening or rendering bright and silver-like, alloys which would otherwise be dull or lifeless, and of producing white alloys with copper, even when less than one part of nickel is used to three parts of copper, gives it a position possessed by no other of the base metals commonly used in the manufacture of alloys.

After copper, it stands first among the common metals for the variety of commercial alloys into whose composition it enters, although it must be admitted that some are used to only a very limited extent; and, if its value as a coating, *i.e.*, for electro-plating, be included, it may be considered first among the common metals for variety of uses, although far behind most in tonnage consumed.

It is also essential in the manufacture of a large variety of resistance wires used for electric furnaces and all classes of electric heaters, a large and rapidly growing use.

The history and progress of the nickel industry are dealt with in a separate Chapter, so far as mining and general development are concerned, but a short description of its growth from the point of view of those who are interested in the smelting, refining and general chemistry and metallurgy of the industry, is not out of place, seeing that the industry depended entirely in the early days on the variety and amount of the non-ferrous alloys which the markets could absorb.

Nickel Industry Preceded by Cobalt

The development of the nickel industry must be considered in conjunction with that of cobalt. The latter metal was, in fact, in the early days, the one of greater commercial interest, and this was entirely due to the intense blue colour which cobalt oxide imparts to silica, and which is taken advantage of in the colouring of glass and porcelain. The term "smalt" or "zaffre" applied to certain roughly made

silicates of cobalt is, in fact, older than the name of either metal, and these silicious compounds were used centuries before the metal itself was isolated.

The Commissioners are indebted to Mr. Frank L. Merry and to Mr. G. S. Boeddicker, Managing Director of Messrs. Henry Wiggin and Co., Ltd., and to many others for previously unpublished information, and have consulted the "History of the Nickel Industry," a paper read by D. H. Browne, January, 1911, before the Society of Chemical Industry, and papers by A. G. Charleton, read before the Society of Arts, 1894 and 1895, where much historical matter has been collected. They have also consulted the Birmingham Handbook, issued by the British Association in 1913, and many older works, such as Timmins' "Resources, Products, etc.," of Birmingham,[1] published in London in 1866. The data collected would occupy too much space, and only a small proportion has been incorporated in these brief notes.

A considerable amount of interesting information as to the early history of nickel and cobalt is contained in Agricola's "De Re Metallica," of which the latest translation from the first Latin edition of 1556, was published by Hoover in 1912. Reference is made there to the mining sermons of Johann Mathesius ("Sarepta oder Bergpostill," Nürnberg, 1562, page 154). He refers to an earth containing an argentiferous mineral called cadmia fossilis, which, when burnt, gave off strong fumes, which worked much evil and mischief, and states that the fumes from cobalt and bismuth ores are the most poisonous, that water from the mines devours the hands and feet of the miners, that the fumes kill those who work in the smelters, and that the ore is poisonous and injurious.

Agricola gives a tabular summary, in which the use of cobalt and manganese as pigments is stated as having commenced prior to 1540 A.D. It would appear that the word "cadmia" had the same meaning as the German "kobelt" in the time of Agricola, who was unaware of the properties of the metal, and was applied to the arsenical cobalt minerals of Schneeberg in Saxony, which are still worked, and which have probably been worked longer than those of any other country.

Although analyses of many of the old blue colours show the presence of cobalt, the Greek and Roman writers do not refer to it, and the first mention of zaffre or cobalt blue was made by Biringuccio in 1540. He did not connect it with the cobalt minerals, but stated that it could only be melted in conjunction with vitreous substances, and that the colouring depended solely upon the amount used. It is interesting to note that Agricola did not appear to connect zaffre with cobalt, but considered its colour to be due to bismuth, which is an invariable constituent of the cobalt ores worked in Saxony.

"The Philosophical Transactions of the Royal Society of London," 1704, No. 293, page 1753, contain a short note by David Krieg, F.R.S., on cadmia or cobalt, a mineral found "in great quantities in the mines about Schneeberg, and some other places of Hermanduria."

Aikin's "Dictionary of Chemistry and Mineralogy," 1807, Vol. 2, contains a good deal of interesting information on the early history of the cobalt industry and states that, at the time of writing (the commencement of the 19th century) the principal minerals worked were those of Norway, Sweden and Saxony, and

[1] The Resources, etc., of Birmingham and the Midland Hardware District, Timmins, London, 1866, p. 145.

the principal use was for the manufacture of smalt or zaffre. He states that one grain of cobalt oxide as then made, would impart a very full blue colour to 240 grains of glass, and it appears that very little attempt was made at that time to separate the nickel from the cobalt.

According to Coghill,[1] about 67,000 lbs. of cobalt oxide was used in the British ceramic industry—the largest in the world—in 1866.

Early Use of Nickel Alloys

Although Aikin refers to the alloys of nickel with other metals, he states that they have been but little examined. He dismisses the copper nickel alloy in four lines, but he refers to meteoric iron as being "scarcely at all oxydable by exposure to the weather"; and adds, "it is highly probable, therefore, that nickel may become a metal of vast importance if its power of protecting iron from rust be fully established."

A search through the patent records of Great Britain shows surprisingly few patents in connection with the use of nickel or cobalt, but the few names which occur as patentees are of men well known in the industry and as metal workers. Those of Muspratt, Vivian, Merry, Parkes and Elkington deserve especial mention, and it is interesting to note that, although the specifications are often vague, many alloys are indicated which are now of importance, apart from the ordinary nickel-copper and like alloys. Among such are those with chromium, referred to in a patent by Alexander Parkes in 1851, and of nickel-copper and iron patented by him in 1844.

The town of Birmingham in England was the pioneer of the cobalt and nickel industry, and the firm founded by Henry Merry of that town and of Longbridge in Worcestershire, was the first to develop the industry. Henry Merry began nickel refining in Birmingham about 1830, and cobalt refining under the invention of Charles Benson of Birmingham, in 1842. They owned nickel and cobalt-matte smelting works in Missouri, U.S.A., in connection with the mine La Motte, and in 1855 joined with John Vivian, who erected the first plant definitely built for the wet separation of nickel and cobalt, at Hafod Isha, near Swansea. This work continued from 1855 until 1882, when the Hafod Isha firm was converted into a limited liability company (H. H. Vivian and Sons, Ltd.) and the works were taken over later on by the Anglo-French Nickel Company, which still operates them. The ores worked both in Swansea and in Birmingham, at which latter place the firm of Evans & Askin, now Henry Wiggin and Company, Ltd., operated (dating from the year 1832), were obtained from all over the world, including Hungary, South America, South Africa, Germany, China, etc., often through the most devious routes, and with every possible precaution to prevent competitors from knowing the place of origin.

Until about 1872, practically the whole of the nickel was obtained from arsenical ores containing considerable quantities of cobalt, and the nickel and cobalt industries worked hand in hand as, in fact, they still do in the case of such ores as those of the Cobalt district of Ontario, and of Schneeberg in Saxony, where the two metals occur together. A very complete description of the nickel-cobalt industry of Schneeberg and of the New Caledonian nickel industry in 1894 and

[1] The Resources, etc., of Birmingham, p. 145.

1895, with many interesting notes as to Canadian nickel and the uses and demand for nickel at that date, has been published by A. G. Charleton.[1]

It may be mentioned here that there is no known case of nickel or cobalt ores occurring in commercial quantities without both metals being present, although, in the case of those worked mainly for nickel, the amount of cobalt present is not sufficient to justify its extraction, and it is usually included and paid for as nickel, and ultimately finds its way into the oxide or metal finally sold.

Beginnings of Nickel Industry

Mr. Henry Merry, the father of Alfred Senior Merry, appears to have been the first maker of an efficient substitute for packfong, which was being shipped from China and sold early in the 19th century for about 13 shillings per pound. He experimented about 1830, in conjunction with Mr. Charles Askin, and ultimately produced "Merry's plate" and "Merry's metal blanc." Large sums of money, stated to have aggregated £20,000, were spent in developing and advertising the alloy, and it obtained a high reputation and a large sale. Prior to the introduction of electro-plating by Elkington, Henry Merry and his brother Theophilus Merry patented, in 1836, a process for silver plating on this metal.

Before 1875, all the nickel and cobalt and their oxides and other compounds were obtained from small deposits, the ores of New Caledonia being of little importance, and those of Canada being then unknown. In all cases, the first metallurgical operation consisted in the production of a speiss (arsenide) or a sulphide (matte), usually the former. If the ores were oxidized ores, they were smelted down with arsenical material and coke dust, in order to introduce the necessary arsenic for the production of a speiss. The enriched product thus obtained was repeatedly calcined and smelted in order to increase the percentage of nickel and cobalt, and to remove the iron. It may, in fact, be stated that the great improvements effected during the last forty years, in the smelting of nickel or cobalt ores and, except in the case of the Mond process, in the refining, have been mainly confined to improvement in plant and enlargement of the scale of operations, the modifications in the metallurgical treatment, although of extreme economic importance, being mainly improvements in established practice and seldom radical. In the case of the cobalt-nickel ores of Ontario, modifications in the process of treatment since the early days when Swansea controlled the market, have been practically nil. The use of chloride of lime or hypochlorite of soda in separating the nickel and the cobalt appears to have been originated at the works of Evans and Askin, now Henry Wiggin and Company, about 1836, and this and the other routine steps in the processes of separation are practically unaltered. The nickel used up to 1875 was obtained almost entirely from nickel-cobalt ores, and contained 97 to 98 per cent. of nickel, the balance being made up of magnesium, silicon and a small proportion of iron. It was produced in the form of cubes or round discs known as rondelles, by mixing the oxide with carbonaceous material and heating in a reducing atmosphere in a reverberatory furnace, exactly as is done at the present day, but on a smaller scale.

[1] J. Soc. Arts, May 4, 1914, pp. 496-513, and May 24, 1915, pp. 609 to 661. See also translation by G. R. Mickle of parts of W. Bruchmuller's work entitled Der Kobaltbergbau und die Blaufarbenwerke in Sachsen bis Zum Jahre 1653, printed as Appendix III, Ont. Bur. Min., Vol. XIX, Part II.

Even bessemerizing to remove iron was carried out in small blast furnaces in Swansea, and was known as "de-ferrating." This brought down the percentage of iron to 0.3 or 0.4, and compared very favourably with modern bessemerizing.

Nickel Coinage and Electroplating Introduced

The production of nickel up to about 1870 was probably not over 200 tons per annum, but the introduction of nickel coinage in Germany after the Franco-Prussian war stimulated the industry, and the production was immediately doubled. The supply of good ore even for this small demand was insufficient, and ores containing so little as 1.5 per cent. nickel were smelted in order to keep pace with the demand. The shortage was, however, only temporary, as the New Caledonia ores were then being exploited, to be followed soon by those of Canada.

The price of nickel was 4s. 6d. per lb in 1830 and 4s. in 1840. By 1849 it had risen to 13s.; but it gradually fell until, in 1866, it again stood at 4s. 6d.

A great impetus was given to the trade by the introduction of electroplating by Elkington, who used nickel silver as his base. Even in 1866, however, the market was small, and the total production is given by Barker as about 200 tons per annum, equivalent to about 1,200 tons of nickel silver.

The oxidized ores of New Caledonia were first smelted with a sulphur-containing material in a cupola furnace, so as to produce a matte containing 50 to 60 per cent. nickel, 10 to 20 per cent. iron and about 30 per cent. sulphur. The material employed as a source of sulphur varied according to the situation of the works. If near a Leblanc soda works, a by-product known as calcium sulphide or blue Billy, was commonly used. If not, gypsum was employed, and in some cases even iron pyrites was used, but not where it could be avoided, as it introduced iron, which had afterwards to be got rid of by the de-ferrating process mentioned above. Prior to the introduction of the converter, the iron was removed by oxidizing in a reverberatory furnace with the aid of barium sulphate mixed with silica.

Although nickel is capable of alloying with all the common metals, the non-ferrous nickel alloys of industrial importance are comparatively few, the principal being the white malleable alloys consisting of nickel and copper, and of nickel, copper and zinc, known under the general names of "cupro-nickel" and "German silver" or "nickel silver."

During the past few years, however, the value of nickel in alloy with a larger variety of metals has become more recognised, and many new alloys are now established in the market, or are being experimented with and used or recommended for specific purposes.

Until quite recent years, but little research was carried out concerning the properties of nickel alloys, even of those that have been in use for industrial purposes for many years, and the published information is still incomplete and unsatisfactory. Several able researches have been recently carried out to remedy this state of things, but although these have added considerably to our knowledge of these important alloys, much still remains to be done.

Nickel-steels and nickel alloys, in which iron is an essential constituent, are dealt with in Chapter VII (Nickel Steel), in which also the effect of carbon on nickel is considered.

The non-ferrous nickel alloys may be considered conveniently under three heads, (1) "Cupro-nickels," or alloys consisting of copper and nickel; (2) "German silvers" or nickel silvers, consisting of copper, nickel and zinc; and (3) miscellaneous non-ferrous alloys of nickel.

1. Cupro-Nickels (Copper-Nickel Alloys)

Nickel unites with copper in all proportions to form a number of useful alloys whose characteristics vary with the relative percentage of each of the constituent metals. It reduces the conductivity and increases the hardness of copper, and copper containing 2 to 3 per cent. of nickel has been found well suited for exposure to high temperatures, i.e., for boiler tubes.

The alloys of nickel and copper are known commercially as "cupro-nickel," "nickel-bronze," and "nickel brass," and also under special trade names such as "Benedict metal."

With regard to the general properties and microstructure of alloys of the copper-nickel series, research has shown that the freezing point falls continuously from the melting point of nickel to that of copper, and the metals form a continuous series of mixed crystals. Therefore, like almost all commercial alloys that are rolled and drawn, they consist essentially of crystals of one substance only, namely, a solid solution. When cast, these alloys exhibit the characteristic structure of quickly cooled solid solutions, but on annealing, the crystallites undergo gradual absorption, and are replaced by the regular crystalline structure of simple metals and homogeneous solid solutions.[1]

With all the alloys in the copper-nickel series, solidification takes place over an interval of temperature, and the smaller this interval, the less heterogeneous is the structure of the alloys when cooled under ordinary conditions.

With the exception of an alloy containing 50 per cent. of nickel, used in the manufacture of so-called German silver, the copper-nickel alloys in general use do not contain more than 25 per cent. of nickel.

The term "cupro-nickel" is usually applied to an alloy containing 80 per cent. of copper and 20 per cent. of nickel, largely used for bullet jackets and other munition purposes.

This alloy, which melts at a temperature of 1190° C., is very uniform in composition, and has remarkable working properties.

From a commercial standpoint, cupro-nickel may be regarded as a comparatively new alloy, but its properties are such that there is little doubt that, when it becomes better known, it will be very extensively used in the metal industries of the future.

Large quantities of cupro-nickel are now being produced in England, mainly for munition purposes, and Sheffield and other places, which did not previously make the alloy, have now become producers.

The Sheffield output, which includes metal made at the Technical Department of the Sheffield University, has gradually increased until it has now been brought up to about 150 tons of 2,240 lbs. per week.

[1] Law, "Alloys," 2nd Edition, London, 1914, p. 219.

In the preparation of cupro-nickel, it is important that copper and nickel of good quality only shall be used. The alloy is made by melting the constituent metals together in the usual way in graphite crucibles, but considerable care is needed in its preparation, owing to the high melting point of nickel. Most of the difficulty is experienced in the casting shop. To ensure sound ingots, the metal must be poured "hot" (about 1300° C.), as unsound ingots result if the metal is cast at too low a temperature. The charge varies from about 80 lbs. to as much as 260 lbs., the average probably being about 120 lbs. Experience proves that large charges are to be deprecated. To ensure sound metal, it is necessary to add a small quantity of some deoxidizing agent, usually about 0.1 per cent. of manganese, to the molten metal shortly before pouring. The quantity of manganese to be added is 0.1 per cent. of the total weight of alloy melted, and not 0.1 per cent. of the nickel content only.

A large variety of deoxidants is in use. Pure manganese is generally employed, but some manufacturers prefer cupro-manganese, consisting of copper 70 per cent. and manganese 30 per cent.

According to G. Lyons, junior,[1] the composition of the cupro-nickel used in the United States for bullet jackets, is usually 85 per cent. copper and 15 per cent. nickel. In preparing this alloy, the American practice appears to be to melt from 150 lbs. to 175 lbs. in graphite crucibles, and to add from 0.25 to 0.5 per cent. of manganese, either as metallic manganese or cupro-manganese alloy (30 per cent. manganese).

A cupro-nickel is manufactured in the United States under the name of "Benedict metal," the government specification for the alloy being copper, 84 to 86 per cent., and nickel 14 to 16 per cent.

Effects of Oxygen and Carbon

In the preparation of copper-nickel alloys, two special dangers present themselves, the first being the presence of oxygen which renders the alloy brittle and practically useless for mechanical treatment, and the second the presence of carbon, for which nickel has an especial affinity. Oxygen is removed, as already mentioned, by a deoxidizing agent, such as manganese, ferro-manganese, copper-manganese or magnesium, and the analysis of copper-nickel alloys should show small quantities (commonly 0.2 to 0.3 per cent.) of manganese or of magnesium.

Carbon, up to a certain percentage, is present as combined carbon, and as such appears to improve the working qualities of the alloy while worked cold, but as soon as the alloy is heated to about 650° or 700° C., especially over a long period, the carbon which up to that temperature had been chemically combined, begins to segregate out as graphite.

Boeddicker[2] states that he has had many such cases where cupro-nickel (25 per cent. nickel) had been made into coinage blanks. Before being sent to the Mint, they were annealed, but on arrival at the Mint, hundreds of blanks were found to have broken into small pieces, and in every case, on dissolving the broken pieces in nitric acid, large flakes of graphite were found in the solution.

[1] "Metal Industry," 1916, Vol. 8, pp. 69-73.
[2] Journ. Inst. Metal, 1912, Vol VII, p. 182.

In this connection it may be pointed out that, according to O. Ruff and W. Martin,[1] the solubility of carbon in molten nickel increases with the temperature up to a maximum at 2,100° C. when 6.42 per cent, of carbon is present, corresponding with the compound Ni_3C. Above this temperature, the solubility is constant. The carbide is said to be very stable, and rapid quenching is sufficient to prevent the decomposition into nickel and graphite completely. Quickly cooled specimens, however, contain a micrographic constituent which is identified with the carbide.

Annealing Cupro-Nickel

With reference to the heat treatment of cupro-nickels, experience has shown that, in hot rolling such alloys, even closer watching of the temperature is necessary than in the case of pure copper. In practice, the annealing of cupro-nickel is usually effected at a temperature of about 700° C.

For the successful annealing of cupro-nickel (15 per cent. nickel) the American practice, according to G. Lyons, junior, consists in heating the furnace to 700° C. (1,300° F) and cutting off the heat as soon as the sheets are pulled in. The metal is allowed to soak for 20 to 30 minutes, during which time the temperature falls to about 509° C, (1,100° F).

The temperature is then again raised to 700° C. and held there until the metal shows clear red all through, when the temperature is reduced and the metal allowed to soak for 15 to 20 minutes, and then pulled out.

R. Adan[2] describes the advantages of copper-nickel alloys over ordinary bronzes, and gives the results of a number of tests on a copper-nickel alloy, including its resistance to corrosion by caustic soda. He does not give the composition of the alloy which he used.

According to H. von Miller,[3] the addition of nickel to bronze increases the shrinkage and tensile strength, and also the difficulty of working. It raises the melting point, and has generally the same properties as cobalt as an addition to bronze.

The conditions of annealing that suffice to render the copper-nickel alloys homogeneous in structure and suitable for rolling purposes have been studied by Sir T. K. Rose.[4]

For this investigation, the alloys were cast into bars either one-half or one-quarter inch thick, and rolled down to one-twentieth of an inch thick, when the maximum hardness was obtained. They were annealed at 100° C. in water or oil, between 100° and 250° C. in oil or glycerine, and above 300° C. by means of an electric heater.

The hardness of the pure metals and of the alloys was measured by the Shore scleroscope using the "magnifier" hammer. On the scale of comparison used, the hardness of lead is 1.5, of soft annealed copper about 13, and of hardened steel die, about 175.

The results obtained for the temperature of annealing, its duration, and the hardness for several copper-nickel alloys are given in the following table:—

[1] Metallurgie, 1912, Vol. IX, p. 143, per Inst. Met., 1912, Vol. VII, p. 272.
[2] Proc. Seventh Int. Congr. Appl. Chem., London, 1909, Sect. IIIA, 103-108.
[3] Metallurgie, 1912, Vol. IX, p. 63-71.
[4] J. Inst. Met., 1912, Vol. VIII, pp. 86-114.

Heat Treatment of Cupro-Nickels

Substance.	Hardness		Lowest temperature at which softening is perceptible °Centigrade.	Temperature at which softening is nearly completed, °C.	
	Max. on rolling.	Min. on annealing.		In 30 min.	In less than 1 min.
Copper	46	13.5	275	360	400
Nickel..............	75	36	300	700	....
Coinage bronze......	65	15.5	200	470	600
Nickel copper alloys.					
20 per cent. Nickel	64	17.5	300	550	....
25 " "	75	23.5	300	650	....
30 " "	77	21.5	300	600	....
50 " "	87	31.5	400	700	....

Bengough[1] has studied the properties of the 80 per cent. copper and 20 per cent. nickel alloy at high temperatures.

The results are given in a table published in that paper,[2] and show that the elongation falls off till a temperature of about 650° C. is reached, and then increases somewhat rapidly, reaching a maximum at about 700° C. It then falls off again up to 750° C., and lastly rises till a temperature of at least 1,010° C. is reached. In practice, the sheet metal is annealed at a temperature of about 700° C.

In the opinion of Boeddicker,[3] who has had great experience in the working of copper-nickel alloys, the elongation curve should be continuous, in other words the elongation should slowly decrease to about 600° C. then increase steadily until the temperature near the melting point (1,190° C.) is reached. It would appear that more experimental work on the 80-20 alloy is necessary.

The hardness and modulus of elasticity of a series of copper-nickel alloys have been determined by N. Kurnakoff and J. Rapke.[4]

The hardness was determined by Brinell's method, using a ball of 9.52 m.m diameter and a load of 485 kilos. The modulus of elasticity was determined by Lermantow's method.[5] It is strictly proportional to the composition.

Nickel-Bronze for Coinage

One of the most important copper-nickel alloys, is that known in Mint language as "nickel-bronze," also sometimes termed "nickel-brass," which consists of 75 per cent. copper and 25 per cent. nickel, and is largely used as a coinage alloy, although it should be pointed out that, at the present time, there appears to be a tendency to substitute pure nickel coins for those of the alloy.

The use of nickel for coinage purposes is extremely ancient. According to A. G. Charleton,[6] nickel was employed for coinage purposes before the Christian era by the Bactrian king Euthydemos, 235 years B.C., and analysis of these coins shows that they were evidently intended to contain 22 to 23 per cent. of nickel

[1] Journ. Inst. Metals, 1912, Vol. VII, pp. 147-149.
[2] l.c.
[3] Inst. Metals, 1912, Vol. VII, p. 181.
[4] Ibid., Vol. XII, pp. 289-290.
[5] Chowlson, Lehrbuch der physik, I, 703.
[6] Journ. Royal Soc. of Arts, 1894.

and 77 or 78 per cent. of copper, thus closely approximating to the proportions of 25 nickel and 75 copper which experience has shown to be the most desirable proportions of these metals for use in coinage.

Dr. Walter Flight[1] has shown that coins of the 2nd century B.C. were struck in an alloy of the following composition, including a little sulphur and tin:—

Copper	77.58 per cent.
Nickel	20.04 " "
Iron	1.05 " "
Cobalt	0.54 " "

In dealing with the question of the use of nickel in currency, it may be well to point out that difficulty frequently arises from the common practice of using the term "nickel" in official and other documents indifferently when referring to coinages of pure nickel or of the alloy, which only contains 25 per cent. of that metal. Confusion would be avoided if the term "nickel-bronze" were used when speaking of the alloy.

The use of nickel for coinage purposes is fully dealt with in Chapter V under the heading of Nickel Coinage.

Monel[2] Metal

This alloy is of especial interest in connection with the nickel industry on account of its being a "natural alloy," made from roasted Sudbury matte, and from the fact that its exceptional properties have been proved by a large number of independent observers and concurred in by users. It is commonly considered by alloy makers, that reliable alloys cannot be made by the reduction of mixed oxides such, for instance, as are present in a roasted matte; and it is true that calamine brass and certain other alloys formerly thus made for the sake of economy, have been abandoned in favour of those manufactured by alloying the pure metals. It is claimed that, in reducing and smelting mixed oxides, there is a tendency for one to be reduced more completely and rapidly than another, and for the product to be irregular and unreliable in composition for this reason, and that this danger has usually proved sufficient to more than balance any saving in cost over the alloying of the separated metals.

On the other hand, the advocates of "natural alloys" claim that this very factor, i.e., the simultaneous reduction of mixed oxides which have never been separated, and which are therefore more perfectly incorporated together than could be the case with any artificial mixture, results in the production of a more homogeneous alloy, and even in one with exceptional properties.

There is no apparent reason why a natural alloy should be better in either respect than the orthodox alloy made by skilled mixing of the pure metals, but it is certain that in the case of the copper-nickel alloy made from roasted nickel matte, a thoroughly reliable alloy is obtainable.

The mixtures of copper-nickel ore smelted by the large companies are fairly uniform in composition, and the matte produced is remarkably regular as regards the ratio of nickel to copper, the percentage of sulphur, and the practical absence of iron and other metals whose presence in a nickel-bronze might be injurious.

[1] Numismatic Chronicle, 1868, p. 305.
[2] So named from the president of the International Nickel Company, Mr. Ambrose Monell.

This matte is readily roasted free from sulphur, and the resultant mixture of almost pure nickel oxide and copper oxide is more readily reduced than nickel oxide alone.

Best Composition of Matte for Monel Metal

The Mond Nickel Company produce a matte averaging about 40 to 41 per cent. of nickel and the same amount of copper, so that its direct reduction to metal would yield an alloy too rich in copper for general direct use. They have, however, no desire to make a nickel-copper alloy, as their process of refining yields large quantities of copper sulphate, which is one of their staple and highly profitable products. Similarly, those who employ the electrolytic method of refining are obliged to produce both nickel and copper, and there is no apparent object in directly preparing an alloy while a sufficient demand exists for the separated metals. Both the Mond and the electrolytic processes also recover the precious metals, and this aspect of the nickel industry is of growing importance.

The position is different in the case of the International Nickel Company, whose process as at present conducted recovers only a comparatively small proportion of the platinum, palladium and other metals of the platinum group, and whose matte is rich in nickel, averaging during the last three years, about 53.5 per cent. of nickel and between 25 and 25.5 per cent. of copper. Even this would be somewhat too rich in copper to produce an alloy of the required composition, but the company employs matte which has been through a preliminary smelting (one of the routine steps in the refining), whereby a portion of the copper has been removed, leaving about 58 per cent. of nickel and about 22 per cent. of copper.

The importance of the Monel metal industry is shown by the production during the company's last three fiscal years (each ending March 31st) :—

1913-1914	3,526,345 lbs.
1914-1915	2,910,606 "
1915-1916	3,982,018 "

It may be pointed out that, prior to the war, the nickel in the Monel metal produced represented about 10 per cent. of the total matte treated by the International Company, and that the company has had so steady a demand for its refined nickel since the war as probably to make them desirous of reducing the output of Monel metal. The figures for 1914 may be ignored, as the effect of the war on the nickel industry was adverse during the first portion, and favourable towards the end. The figures for the other two years, however, show the importance of an alloy whose annual production largely exceeds that of any other non-ferrous alloy made under a trade name.

Monel metal was introduced for the purpose of enlarging the market for nickel, and the International Nickel Company had not only to find or make a market for the alloy, but to overcome the trade prejudice against such a "natural alloy." The fact that they have succeeded affords considerable encouragement to those who are hopeful of making nickel-copper steel direct from Sudbury ore or slag, a project which is dealt with in the chapter on Nickel Steel, and which is of much interest and importance to the metallurgist.

The composition of Monel metal does not vary largely from nickel 68 per cent., and copper 30 per cent., with about 1.5 per cent of iron.

An analysis of a sample bar received in 1911 by Mr. Leonard Archbutt,[1] of Derby, England, gave the following results:—

Analysis of Monel Metal (Sample Bar)

	per cent.
Copper	33.18
Nickel	64.32
Iron	1.82
Aluminium	.02
Zinc	.05
Manganese	.20
Silicon	.33
Phosphorus	.04
Sulphur	.04
Carbon	.05
	100.05

Oxygen (loss of weight on heating to redness in hydrogen), not more than a trace.

Arsenic, Lead, Silver, Tin	Nil.

Physical Tests

——	Maximum stress tons.	Elongation per cent. in 2 in.	Contraction at fractures.
60° F	32.25	46.30	69.20
400° F	28.15	44.65	68.35
600° F	27.40	41.75	66.25

At that time, the composition of parcels sold appears to have varied somewhat, but the output is now of much greater regularity. The following analyses by R. H. Gaines[2] show the general run of composition:—

Average Composition Monel Metal 1911

——	Cast metal per cent.	Rolled metal, per cent.	Forged metal, per cent.
Copper	26.59—27.53	24.76—26.99	26.69—26.83
Nickel	68.10—68.50	68.48—69.83	69.45—69.54
Iron	2.16— 3.33	2.07— 2.44	2.13— 2.19
Carbon	0.25— 0.43	0.28— 0.44	0.17— 0.19
Silicon	1.08— 1.41	0.12— 0.37	....—....
Maganese	0.11— 0.49	1.26— 0.49	1.38— 1.50
Cobalt	trace	trace	....—....

NOTE.—Cast metal .... 8 samples.
Rolled metal .... 6 samples.
Forged metal .... 3 different portions of a billet.

[1] Private communication.
[2] J. Ind. Eng. Chem., 1912, Vol. IV, pp. 354-8.

More recent analyses by Parker[1] are as follows:—

Later Analyses

—	Shot used for castings, per cent.	Bar ½ inch. per cent.	Bar ¾ inch. per cent.	Bar 1 inch. per cent.	Turbo-blading, per cent.
Nickel	67.10	65.87	66.03	66.03	67.10
Copper	29.00	27.81	27.55	28.53	27.00
Iron	3.90	3.08	3.44	3.09	3.85
Manganese	trace	2.38	2.38	1.82	1.87
Aluminium	nil	0.37	0.26	0.18	....
Silicon	....	....	....	....	0.14

According to Gaines, the strength and other physical properties of the alloy are affected chiefly by the heat treatment, the variations in the proportions of the constituents within the limits in which they occur having comparatively little influence.

Difficulty is sometimes encountered in obtaining sound castings of Monel metal, chiefly owing to dissolved oxides and gases, but an addition of two ounces of magnesium per 100 lbs. of alloy before pouring is said to remedy the difficulties due to these causes.

In appearance, Monel metal resembles pure nickel. It takes a brilliant finish and, on prolonged exposure, or on heating, the polished surface assumes a grey tint which can be removed by a polishing cloth. The melting point of the alloy is 1360° C. and the shrinkage is ¼ inch per foot.

The physical and mechanical properties of Monel metal are given in a bulletin issued February, 1916, by the Supplee-Biddle Hardware Company, of Philadelphia, as follows:—

PHYSICAL PROPERTIES OF MONEL METAL

Melting point .... 1,360° C. (2,480° F.)
Specific gravity (cast) 8.87
Weight per cu. in. (cast) ....0.319 lbs.
Weight per cu. in. (rolled) ......0.323 lbs.
Coefficient of expansion.
(20° C.—100° C.)....0.00001375 per 1° C.
Electrical resistivity....256 ohms per mil-ft.
(Temp. coefficient ....0.0011 per 1° F.
Electrical conductivity.4 p.c. (Copper 100 p.c.)
Heat conductivity ..96½ p.c. that of copper
Shrinkage ....¼" per foot
Hardness cast material
20-23 (shore scleroscope)
Hardness hot rolled rods
27 (average shore scleroscope)
Modulus of elasticity, 22,000,000—23,000,000
Torsional tests on rods (average).
Shearing stress—Lbs. per sq. in. on remotest fibres:
At elastic limit 31,796
At ultimate load 79,053

Compression tests on rods.
Elastic limit.. .... 25,000 to 32,000 lbs. per sq. in.
Compression tests on castings.
Elastic limit ...... 12,000 to 25,500 lbs. per sq. in.
Tensile tests on castings (average of 172 heats tested for Isthmian Canal Commission).
Yield point ..... 37,093 lbs. per sq. in.
Tensile strength ... 72,281 do
Elongation in 2 in. .... 34 p.c.
Reduction of area .... 32 p.c.
Tensile tests on rods (average of last 100 tests made in 1913).
Yield point ...... 55 587 lbs per sq. in.
Tensile strength .. 88,232 do
Elongation in 2 in. .... 42 p.c.

[1] J. Inst. Metals, 1915, Vol. XIV, p. 52.

SPECIFICATIONS FOR THE INSPECTION OF MATERIALS

U. S. Navy (as in force January 1, 1914)

Sand Cast Materials

	Ultimate Tensile Strength lbs. per sq. in. Minimum	Yield Point lbs. per sq. in. Minimum	Elong'n per cent. in 2 in.
Monel metal	65,000	32,500	25
Manganese Bronze	65,000	30,000	20
Gun bronze	30,000	15,000	15
Steel—Special ...	90,000	57,000	20
" Class A ..	80,000	35,000	17
" Class B ..	60,000	30,000	22

Rolled Materials

	Ultimate Tensile Strength lbs. per sq. in. Minimum	Yield Point lbs. per sq. in. Minimum	Elong'n per cent. in 2 in.
Monel metal—			
1" and below ..	84,000	47,000	25
Above 1" to 2½"	80,000	45,000	28
Above 2½"	75,000	40,000	32
Manganese bronze—			
1" and below..	72,000	36,000	28
Above 1"	70,000	35,000	30
Rolled naval brass—			
Up to ½"	60,000	27,000	35
½" to 1"	58,000	26,000	40
Over 1"	54,000	25,000	40

INFLUENCE OF TEMPERATURE UPON TENSILE STRENGTH

Rolled Rod Brass

Fahr.	Tensile Strength	Elastic Limit	Elongation per cent. in 2 inches	Red'n of Area
70°	54450	45000	16.4	18.0
300°	52700	43200	26.6	34.2
450°	49000	39100	21.9	26.0
525°	—	—	—	—
600°	35050	23735	14.9	17.8
750°	18740	15050	17.2	21.3
950°	—	—	—	—
1030°	—	—	—	—

Rolled Monel Metal

Fahr.	Tensile Strength	Elastic Limit	Elongation per cent. in 2 inches	Red'n of Area
70°	104900	78350	31.3	61.7
300°	97400	58500	29.7	57.8
450°	97800	58600	29.7	51.0
525°	96400	58400	32.8	59.5
600°	89600	57950	32 8	59.5
750°	67600	42550	28.1	58.1
950°	—	—	—	—
1030°	47200	26800	28.1	60.7

Rolled 30 per cent. Nickel Steel

Fahr.	Tensile Strength	Elastic Limit	Elongation per cent. in 2 inches	Red'n of Area
70°	94498	39850	51.2	59.8
300°	97000	31700	64.1	65.0
450°	84950	32250	62.5	65.0
525°	83000	26200	59.4	66.8
600°	69575	25650	56.3	72.6
750°	45650	21100	43.0	59.4
950°	—	—	—	—
1030°	36350	15500	37.5	55.7

Cold Rolled Shafting (Bessemer)

Fahr.	Tensile Strength	Elastic Limit	Elongation per cent. in 2 inches	Red'n of Area
70°	82800	76800	21.9	49.5
300°	91850	77100	21.9	39.1
450°	96083	72850	21.9	38.7
525°	96250	75300	18.8	37.5
600°	88525	54275	25.0	44 2
750°	—	—	—	—
950°	39250	30400	35.2	78.0
1030°	—	—	—	—

INFLUENCE OF TEMPERATURE UPON TORSIONAL STRENGTH

⅞" Rolled Monel Metal

Fahr.	Torsional Strength	Elastic Limit	Twist
70°	94610	45510	12 and 150
385°	83030	33940	5 and 0
600°	72290	31300	5 and 205
800°	40610	10910	6 and 240

Tobin Bronze

Fahr.	Torsional Strength	Elastic Limit	Twist
70°	61200	26850	2 and 155
385°	36560	9800	4 and 0
600°	9920	1630	4 and 15
600°	8860	3270	3 and 255
800°	—	—	—

35 per cent. Carbon Cumberland Cold Rolled

Fahr.	Torsional Strength	Elastic Limit	Twist
70°	83840	42540	2 and 280
385°	76650	36800	2 and 30
600°	15920	2040	8 and 230
600°	17100	4090	9 and 195
800°	7180	1630	39 and 195

Elephant (Phosphor) Bronze

Fahr.	Torsional Strength	Elastic Limit	Twist
70°	70000	34250	12 and 95
385°	51020	21240	1 and 215
600°	19920	6560	15 and 200

INFLUENCE OF TEMPERATURE UPON TORSIONAL STRENGTH—Continued

Vanadium Tool Steel.				Delta Metal			
70°	137295	54100	0 and 345	70°	61630	26940	0 and 180
385°	124080	27550	1 and 250	385°	42860	14600	3 and 235
600°	67710	17820	0 and 320	600°	3265	1360	4 and 300
800°	——	——	——				

Rolled Rod Brass				Parsons Manganese Bronze			
70°	51200	32600	2 and 225	70°	61630	22040	2 and 5
385°	43780	22180	2 and 185	385°	37630	13060	3 and 110
600°	14190	4100	5 and 40	600°	8980	3260	2 and 10
800°	——	——	——				

Monel metal is now produced commercially in a great variety of forms, but it is in the form of sheets, rods and castings that its greatest utility is found. Its chief uses and possibilities are in connection with the engineering industries, owing to its strength and non-corrosive properties compared with the non-ferrous alloys, such as brass and bronze, now in common use.

Monel metal is largely used in the United States for battleship propellers, whilst in Germany, it has been adopted for locomotive fireboxes, since its strength is but little impaired by high temperatures (1000° F. or 538° C.), a very important feature. At 1000° F., Monel metal retains 80 per cent. of its tensile strength and elastic limit, while steel retains 70 per cent. and manganese bronze only 60 per cent.; copper has, at 780° F., already lost 60 per cent. of its strength. It can be cast up to a weight of 30,000 lbs. in one piece.

Pump rods and ore dressing screens are also made of Monel metal with satisfactory results.

W. E. Oakley[1] describes some large scale casting work at the Bayonne Casting Company Works, Bayonne, N.J. (propellers, pump rods, turbine blades, etc.), and Prof. W. Campbell[2] has published some valuable notes regarding the nature and properties of Monel metal, from which some of the particulars given above have been taken.

One of the chief causes of the efficiency of Monel metal for screw propellers, is its high modulus of elasticity which, as shown above, is 22,000,000 to 23,000,000.

Monel metal may be forged when heated to a temperature of 600° to 900° C., preferably in a muffle furnace. In the form of sheets, Monel metal is annealed by heating to a temperature above 875° C., the degree of softness obtained being dependent upon the extent that the sheets are heated above this temperature. Rods are annealed by heating to any temperature between 800° C. and 1000° C., and the rods are progressively softened by increased temperature. Heating above 1000° C. does not give any additional softness.

It is stated that Monel metal should be annealed, whenever practicable, buried in charcoal in air-tight boxes, so as to prevent the formation of oxide.

Pickling is best effected in a solution of ferric sulphate heated to a temperature of 100° F. to 140° F.

[1] Metal Ind., 1914, No. 2, p. 61.
[2] Trans. Can. Min. Inst., 1913, pp. 241-254.

Resistance to Corrosion

Resistance to the action of salt water, to acid and alkaline solutions, and to atmospheric corrosion, constitutes a valuable property of the alloy. For this reason, it has been employed for marine work and for the high tension insulators of the Panama Canal electric supply. In sea water, where bronze, copper or steel, exposed alternately to the action of air and salt water, become rapidly pitted, Monel metal remains almost unaffected.

The losses sustained by Monel metal by immersion for 6 weeks in solutions of sulphuric acid (10 per cent.), copper sulphate (10 per cent.), and sulphuric acid with copper sulphate (each 10 per cent.), were found by Croasdale[1] to be only 2.81, 1.99 and 4.88 per cent., respectively.

The effect of boiling acetic acid of various strengths on Monel metal sheet, compared with copper sheet, indicate that, under similar conditions of time and strength of acid, etc., copper sheet is attacked by boiling acetic acid approximately twice as fast as Monel metal.

The results of a number of tests made with a view to determining the resistance of Monel metal to the water of mines have been published by A. F. Crosse, of South Africa. He dropped very acid water (0.04 per cent. of free sulphuric acid) from the Ferreira Deep mine, for 6 days continuously, on a piece of Monel metal and also on iron. Whilst the latter soon corroded, the Monel metal remained unaffected—though stained by the deposit from the evaporated water—so that the action of ordinary mine water on Monel metal may be regarded as inappreciable.

After two days' immersion in a 3.5 per cent. solution of sulphuric acid, a Monel metal rod had only lost 0.04 grm. of copper from an exposed surface of 40 sq. cm., whereas, in the check experiment with iron, a saturated solution of the iron salt was obtained. At that rate it would take 2,000 days to dissolve a thickness of one one-thousandth of an inch of the Monel metal.

In a 0.12 per cent. solution of potassium cyanide, 0.13 grm. of copper was dissolved from an exposed surface of 112 sq. cm. of Monel metal in 5 days, iron being unaffected.

Washers of Monel metal, weighing 39.88 grms., were immersed for 5 days in a 0.05 per cent. of free hydrocyanic acid and lost 0.01 grm. of copper (exposed surface about 30 sq. cm.). Iron washers under the same conditions lost 0.05 grm. out of 40 grms. This test is interesting, as the conditions are similar to those of metal exposed to the action of vapours or splashes from a cyanide solution.

Owing to the remarkable resistance to corrosion shown by the nickel-copper alloys containing high percentages of nickel, attempts have naturally been made to adapt these alloys to various engineering purposes. If, for example, part of the nickel in an alloy similar to Monel metal, is replaced by tin, the ductility of the alloy is lowered, but it possesses great resistance to corrosion, a low coefficient of friction, and is unaffected by moderately high temperatures. It is, therefore, a very valuable alloy for the construction of such parts as the seats and discs of high-pressure steam valves.

An alloy for this purpose containing approximately 54 per cent. of nickel, 33 per cent. of copper, and 13 per cent. of tin, known as Platnam metal, is due to the enterprise of Messrs. J. Hopkinson & Company, who were the first to realize the importance of these alloys.[2]

[1] Eng. and Min. J., 1914, 98, 873.
[2] Law. "Alloys," 2nd Edit., 1914, p. 220.

Other copper-nickel alloys of industrial importance consist of copper containing comparatively small proportions of nickel. An alloy consisting of 95 per cent. copper and 5 per cent. nickel has been adopted by the British Government for the driving bands of projectiles. Copper containing from 2 to 5 per cent. of nickel has been used for firebox stays with good results. The alloy of copper with 2 per cent. of nickel is used to a considerable extent for this purpose in place of copper-arsenic alloys, both on account of its greater tenacity at high temperatures and its comparative freedom from oxidation. It has been stated by Sir Gerard Muntz that, when engineers have once used this alloy, they rarely return to the use of copper-arsenic alloys, experience having shown that the oxidation of the copper-nickel alloy is much less than with copper-arsenic.

2. Nickel Silvers (Copper-Nickel-Zinc Alloys)

The white, ductile triple alloys of copper, nickel and zinc, which are known commercially as nickel silver or German silver, are of somewhat widely varying composition, and are made in a number of different qualities, the most usual of which contain about 55 to 60 per cent. of copper, 15 to 20 per cent. of nickel, and 20 to 30 per cent. of zinc.

Packfong

An alloy composed of these three metals was known in early times in China, where it was used for the manufacture of gongs and other musical instruments, and whence it was exported to Europe in considerable quantities especially during the 18th century, under the name of "pack-tong" or white copper; pack meaning white, and tong being the Chinese for copper. The word is usually written packfong, which may now be taken as the accepted spelling.

Packfong seems to have been recognized as a triple copper-nickel-zinc alloy in 1776, when Engeström published what appears to have been the first analysis. The following table gives this analysis (1), together with (2) one by Dr. Fyfe, of Edinburgh (1820), (3) one taken from Geologie et Mineralogie Appliquées, by Henri Charpentier (1900), and (4) an analysis of Luhler alloy (1825):

	Per cent. (1)	Per cent. (2)	Per cent. (3)	Per cent. (4)
Nickel	15.63	31.9	25.00	8.75
Copper	43.75	40.4	50.00	88.00
Zinc	40.62	25.4	25.00	....
Iron	....	...	....	1.75

Analysis (4) is of interest as it refers to a natural alloy produced at Luhl by smelting a nickeliferous copper ore. It was alloyed with excess of zinc, and produced what was sold as a substitute for packfong under the name of "Luhler white copper."[1]

It will be seen that analysis of individual specimens varies considerably, from which it appears highly probable that the alloy was the product of some "cementation" process, much as calamine brass was, or was obtained by the direct

[1] Brandes Schweiz. Ann., V. 39, 1, 7, and Annales des Mines, 1825.

smelting of a complex ore, as in the production of Monel metal at the present time, and wide variations in the percentage of the three principal metals which enter into its composition are, therefore, not surprising. It must also be borne in mind that nickel as a distinct metal was not separated until 1774.

Nickel Silver

The utilization of nickel for the manufacture of nickel silver marked an important stage of development in the history of the metal. The manufacture of the alloy was commenced on a large scale at Berlin about the year 1824, when nickel obtained a recognized position, Brandes having shown, the previous year, the exact composition of the alloy.

At the present time, nickel silver is of such general utility that articles made of it are everywhere to be found in household use. It is prepared largely as a basis metal for electro-plating, and as a substitute for silver, and consists of copper, zinc and nickel in proportions varying with the purposes for which it is intended.

Nickel silver probably exists under a greater number of names than any other alloy, as different manufacturers employ fanciful names to denote alloys containing different proportions of the constituent metals, which they consider best suited to produce an alloy of good white colour.

Among the numerous names which have been used in England, the most common is nickel silver, while others are argentan, silveroid, silverite, Nevada silver, Potosi silver, Virginia silver, amberoid, electrum, etc.; while, on the continent of Europe, it is known as maillechort (after Maillet, who introduced it into France), alfenide, argiroide, neu-silber, weiss-kupfer, etc.

Even before the war, the Alloys Nomenclature Committee appointed in 1914 by the Institute of Metals, London, suggested the alteration of the names of the alloy, since it is neither "German" nor "silver," but German silver and nickel silver have been so long in use in the works, and have become so familiar to the general public, that it is doubtful whether either will cease altogether to be used.

If we adopt the nomenclature which indicates the true nature of the alloy, nickel silver, strictly speaking, would be a zinc-cupro-nickel, but it might be more convenient to call it a nickel brass, were it not for the fact that this name has unfortunately become associated with the alloys of the copper-nickel series containing no zinc.

The various grades of nickel silver in general use in the trade, are known in trade circles as firsts, seconds, thirds, and fifths, which contain approximately the following composition as to nickel; firsts, 20 per cent.; seconds, 16 per cent.; thirds, 12 per cent.; fifths, 7 per cent.; the content of copper appears to vary between 56 and 59 per cent.[1]

The alloy known as seconds is used by many firms as the basis metal for electro-plate wares of best "A.1." quality. It is also largely employed for the manufacture of best quality so-called nickel silver spoons and forks, etc. A number of electro-plate firms in England, however, turn out nearly all their work plated upon nickel silver containing more than 16 per cent. of nickel, and the Admiralty and several of the large steamship and hotel companies, and many other commercial

[1] McWilliam & Barclay, Journ. Inst Metals, 1911, Vol. V, p. 214.

concerns specify a high nickel alloy. The Admiralty specification is for basis metal containing 19 per cent. of nickel. The large American and Canadian railway companies demand a basis metal containing 21 and 22 per cent. nickel. The properties considered in deciding upon the grade of nickel silver to be used as a basis metal for electro-plating are strength, colour and malleability. The high-grade nickel alloys have the advantage of greater strength and whiteness, and they more satisfactorily withstand, under the most trying conditions, the wear and frequently very rough use in hotels and restaurants.

The following table[1] shows the composition of the principal varieties of nickel silvers in Birmingham, Sheffield and elsewhere, with their trade names:—

Composition of Chief Varieties of Nickel Silver

Name	Composition		
	Nickel, per cent.	Copper, per cent.	Zinc, per cent.
1 Extra white metal	30	50	20
2 White metal	24	54	22
3 Arguzoid	20.5	48.5	31
4 Best best	21	50	29
5 Firsts or best	16	56	28
6 Special firsts	17	56	27
7 Seconds	14	62	24
8 Thirds	12	56	32
9 Special thirds	11	56.5	32.5
10 Fourths	10	55	35
11 Fifths, for plated goods	7	57	36
12 Electrum	26	51.5	22.5

Mechanical Properties

The relative proportions of copper, nickel and zinc, especially of the latter metal, have considerable influence on the mechanical properties of the resulting alloys. As the result of a number of experiments on the relative composition of nickel silver, Hiorns[2] concludes that, for alloys containing less than 16 per cent. of nickel, the quantity of zinc should be 30 per cent. in order to give the best results, while, with alloys containing more than 16 per cent. of nickel, the quantity of zinc should be less than 30 per cent. As a general rule, an increase in the nickel content of nickel silver alloys results in increased strength, and the colour approaches more nearly the white of silver, while the malleability decreases.

When carefully prepared, nickel silver works well between the rolls and under the stamps, as it possesses considerable tenacity, malleabilty and ductility. It also possesses the power of resisting certain chemical influences, especially in the case of alloys of high nickel content.

The microscopical examination of the nickel silver alloys shows that the addition of zinc to the copper-nickel alloys is not attended with the formation of

[1] Nos. 1 to 11—Hiorns' Mixed Metals, 2nd Edit., p. 293, No. 12—Journ. Inst. Metals, 1912, Vol. VII, p. 193.

[2] Mixed Metals, 2nd Edit., p. 290.

compounds, and the resulting triple alloys consist of a single homogeneous solid solution. They may be regarded either as brasses containing nickel in solution, or as copper-nickel alloys containing zinc in solution. As in the case of most solid solutions, the alloys are hardened by mechanical treatment, and are softened by annealing.

In addition to its use as a basis metal, large quantities of nickel silver in the form of sheets, wire, and rods are now used for railway work on many lines in Great Britain and abroad. Also, owing to the enormous increase in the price of tin within recent years, nickel silver has frequently been used in place of Britannia metal (an alloy of tin, antimony and copper), and whereas, formerly, nickel silver was hardly ever used in any way other than for stamping or raising, manufacturers have begun to work it similarly to Britannia metal by spinning and pressing. It is, however, very difficult to get nickel silver to stand these severe demands, and although copper-nickel-zinc alloys have recently been the subject of several able researches, much experimental work yet remains to be done to determine the best composition of alloy and method of treatment, to meet these requirements.

Owing to the high temperature required for the fusion of nickel and the low melting point and ready oxidability of zinc, the preparation of nickel silvers is attended with a considerable loss of zinc, and special care is accordingly required in their manufacture.

Manufacturing Processes

In the manufacture of nickel silver in England, the separate metals are not melted together, but are used in the form of binary alloys, part of the copper being melted with the nickel to produce cupro-nickel, and part with the zinc to form brass. The brass is cast into thin plates, broken up whilst hot, and then added to the molten cupro-nickel. This method answers the double purpose of more readily producing a homogeneous alloy, and of lessening the oxidation of the zinc.

Some manufacturers alloy the nickel with copper in the proportion of 1 part by weight of nickel to 2 parts of copper, while others use equal weights of the two metals. Nickel in the form of 50 per cent. cupro-nickel dissolves in the molten brass more readily than nickel alone. The zinc is commonly alloyed with the copper in the proportion of 2 parts of zinc to 1 part of copper.

The melting is done in the usual way in graphite crucibles, either in coke or gas-fired furnaces. Stirring is commonly performed by means of an iron rod, but this is undesirable, and a carbon rod should be used. Iron rods, if used, should be protected by a coating of borax and fire-clay. Shortly before pouring the metal, a small quantity, ranging usually from 0.1 to 0.25 per cent., of metallic manganese or some other deoxidant, should be added to ensure thorough deoxidation of the alloy and production of sound metal. The metal is cast in iron moulds, which vary in size according to requirements.

For ingots which are intended to be rolled into sheets, the moulds are from 16 to 18 in. in length, 1 to 1¼ in. thick, and from 4 to 5 in. wide; while for ingots for wire drawing, the sizes are from 4½ to 5 feet long, 1¼ in. thick, and 3¼ in. wide. The method of casting is the same as in the case of cupro-nickel and brass.

According to H. Kloss,[1] in a more recent method of preparing nickel silver, a mixture of 3.75 parts of copper, 0.25 parts of zinc, and 1.5 parts of nickel, is introduced into a red-hot crucible, and melted rapidly under charcoal, and the remainder of the metal is then added in the form of small fragments.

The same authority states that the German practice in preparing nickel silver and similar alloys, is to place alternate layers of copper, nickel and zinc in the crucible, to cover with charcoal, and to melt as rapidiy as possible. Only a third of the zinc and nickel is added in this way, the remainder being added after the whole is fluid. Owing to the volatility of zinc, it is almost impossible to get two ingots that agree exactly in composition, however much care is taken in the selection of the metals used in the melting.

Impurities and Their Effects

The impurities most frequently met with in nickel silvers are derived from the metals used, and consist of small quantities of iron, lead and tin.

The effect of iron is to increase the strength, hardness, and elasticity of the alloy so that, for some purposes, it is an advantage to add 1 or 2 per cent. of iron.

Both tin and lead render the metal brittle and unfit for rolling. Lead, however, although not permissible in metal that is intended for rolling, confers beneficial properties when the metal is to be cast and subsequently worked, so that it is purposely added to the extent of two or three per cent. in such cases. Besides the usual impurities and dissolved oxygen, carbon plays an important part in these alloys as in the case of cupro-nickels, to which reference has already been made.

From a recent investigation on nickel silver by F. C. Thompson[2] it would appear that oxygen, when present in the cast metal, occurs as a finely disseminated oxide, probably zinc oxide.

The addition of manganese, or other deoxidizer during melting, greatly reduces the size of the crystal grains, and lessens the tendency to "riffling" or corrugation, during spinning, etc. Riffling appears to be due to adjacent crystals being thrust over one another.

The improvement effected in the mechanical properties of nickel silvers by the use of deoxidants is shown in the following table, which gives the results obtained by C. W. Leavitt[3] in ordinary foundry practice, by using pure magnesium in stick form as a deoxidizing agent. The magnesium was wrapped in copper foil, plunged to the bottom of the crucible and kept there until molten, but some makers add the magnesium in the form of a magnesium-copper alloy.

[1] Giesserei-Zeitung, 1912, Vol. IX, pp. 247, 410—Abstract in J. Inst. Met., 1912, Vol. VIII, p. 325.
[2] Trans. Chem. Soc., 1914, Vol. 105, p. 2342.
[3] "Metal Industry," 1909, Vol. I, p. 210.

Effect of Deoxidants

Composition—per cent.			Metallic Magnesium added, per cent.	Tensile Strength, pounds per square inch	Elongation, per cent.
Copper	Nickel	Zinc			
60	14	26	none	30,200	2.5
60	14	26	0.1	35,200	8.5
52	22	26	none	27,800	3.5
52	22	26	0.1	29,100	10.75
55	26	19	none	30,000	7.0
55	26	19	0.1	31,700	11.0
55	25	18	none	24,900	7.25
55	25	18	0.1	33,700	12.25

NOTE.—The two last quoted samples each contained also 2 per cent. of iron.

The preparation of a satisfactory copper-nickel-zinc alloy involves the reduction of the cored crystals, which are very persistent in nickeliferous alloys after casting, and which impart brittleness to the metal, to a structure consisting of allotriomorphic crystals. This transformation in the crystal structure is brought about by careful annealing.

Heat Treatment of Nickel Silver

The annealing is effected in reverberatory furnaces so constructed that a reducing atmosphere is, as far as possible, maintained, and oxidation kept at the minimum. The temperature of annealing is of great importance, and it is only within the last few years that research has been directed to this subject. In this connection, the work of O. F. Hudson[1] and F. C. Thompson[2] should be mentioned. The annealing temperature has been found to vary from 700° to 900° C. according to the composition of the alloy, the higher temperature being employed for alloys of high zinc content.

The results obtained in ordinary works practice, show that annealing from 20 minutes to an hour at a temperature of about 750° C., is quite sufficient to render nickel silver alloys soft enough for all purposes, although a shorter time with a higher temperature is frequently employed for thin sheets. Where however, the sheets are about ½ in. to ¾ in. thick, a short time at a high temperature is impossible, and a longer time at a lower temperature is necessary to heat the metal evenly all through.

The test of softness applied in practice, is the capability of the metal to be rolled and stamped.

Every effort is made in works practice to employ the temperature most suitable for annealing the particular work in hand, so as to limit, as far as practicable, the surface oxidation and formation of scale, the subsequent removal of which is the cause of considerable trouble and expense.

With a view to preventing oxidation as far as possible, special forms of muffle or retort annealing furnaces have been introduced within recent years. The Bates

[1] J. Inst. Metals, 1913, Vol. IX, pp. 109-112.
[2] Ibid., 1916, Vol. XV.

and Peard furnace in use at the Royal Mint, London, and also in several nickel silver works, for annealing purposes, is of this type.

The ends of the retort are closed from the air by a water seal, the annealing being effected in an atmosphere of steam, which prevents the formation of scale, and reduces oxidation to a minimum.

The effect of annealing at different temperatures on a series of copper-nickel-zinc alloys, has been investigated recently by F. C. Thompson.[1]

Tensile tests made on the cast alloys, containing 60 per cent. of copper and from 7 to 28 per cent. of nickel, showed a distinct increase of strength as the nickel content rose, without, however, any appreciable change in the elongation or reduction of area. Change of nickel content had very little effect on the strength under compression, of the cast alloys.

Deoxidation of the molten alloys with 0.25 per cent. of manganese produced a marked improvement in the rolling properties.

Torsion and Brinell hardness tests showed the temperature at which annealing began. It rose with increasing nickel content from 370° C. with 7 per cent. nickel alloys, to 600° C. with 28.6 per cent. nickel alloys. The hardness curves showed a sharply localized peak about 330° C. The influence of time on the temperature at which annealing started was negligible, although the temperature of the critical point was slightly lowered by "soaking."

Hardness and alternating stress (Arnold) tests made on commercial samples of nickel silver indicated that the impurities usually present, are practically without effect on the properties at the temperature of annealing. The tendency to "burn" during annealing of the commercial alloys tested was increased (a) by increasing the nickel content, (b) as the ratio of zinc to copper increased, and (c) with the amount of impurities present. Metal which had been overheated during the annealing, was rendered brittle through the re-formation of the large cored crystals which are obtained after casting. This fault could be rectified by re-annealing at a lower temperature, which caused a transformation in the crystal structure and a removal of all dendritic markings.

With regard to the output of nickel silver, it is computed that, in Sheffield, where large quantities of electro-plated nickel silver cutlery and hollow-ware, and also of unplated nickel silver cutlery are made, the consumption of nickel silver is some 2,000 tons (of 2,240 lbs.) per annum. Of this quantity, however, only about one-third. i.e., 650 tons, can be estimated as new metal, scrap being melted over again to the approximate extent of two-thirds of the whole consumption.

Allowing an average composition of 20 per cent. nickel in the alloys made, the actual weight of pure nickel used annually in the nickel silver trade of Sheffield would only be about 130 tons, based on the output of 650 tons of new metal.

Special Copper-Nickel-Zinc Alloys

Alloys of copper-nickel-zinc are used as hard solders for soldering nickel silver, but they contain a larger proportion of zinc than nickel silvers so as to render them more fusible.

[1] Journ. Inst Metals, London, 1916, Vol. XV.

The following are examples of the composition of the alloys used for nickel silver solders:—

Composition of Hard Solders

—	Description of Solder				
	Hard	Hard	Hard	Medium	Soft
Copper, per cent.	47	38	38.5	34.5	36
Nickel "	42	50	48.0	56.0	56
Zinc "	11	12	13.5	9.5	8

For cast work, which only requires to be filed and turned, the best copper-nickel-zinc alloy for beauty, lustre and working properties is stated, by makers of nickel silvers, to be an alloy consisting of 46 per cent. copper, 34 per cent. nickel and 20 per cent. zinc. Sometimes lead to the extent of one to three per cent. is added for cast work.

The alloy known as "Argozoil" contains both lead and tin, and can only be used for castings, as it cannot be rolled. Its composition is as follows:—

	Per cent.
Copper	54
Zinc	28
Nickel	14
Tin	2
Lead	2

Several nickel silvers containing a small quantity of aluminium have been suggested, the aluminium acting mainly as a deoxidizer. According to Law[1] an alloy of this description containing 57 per cent. copper, 20 per cent. nickel, 20 per cent. zinc, and 3 per cent. aluminium, is largely used for typewriter parts. Magnesium is sometimes used for the same purpose, and an alloy containing 75 to 90 per cent. of copper, 10 to 25 per cent. of nickel, and 1 to 2 per cent. of magnesium, is said to be largely used in Germany.

According to H. Williams,[2] an alloy known as turbadium bronze, contains approximately copper 48, zinc 46.45, tin 0.5, lead 0.1, iron 1, aluminium 0.2, manganese, 1.75, and nickel 2 per cent. It has a tensile strength of 35 to 42 tons per sq. in., and elongation (on 2-in. test-piece) 14 to 20 per cent. It is used for making solid propeller castings, since it is not corroded appreciably by sea water.

3. Miscellaneous Non-Ferrous Alloys of Nickel

Nickel enters into the composition of a number of important alloys not included under the first two heads.

It has proved to be a valuable constituent in alloys of high electrical resistance, and alloys specially prepared to resist the corrosive action of acid liquids, etc.

The non-ferrous alloys employed in the manufacture of electrical resistances constitute an important class, to which new alloys are constantly being added.

[1] "Alloys," 2nd Edit., 1914, p. 224.
[2] Chem. News, 1915, 112, 175-176.

Many of these are placed on the market under special names, such as "platinoid," which is a nickel-silver containing 1 or 2 per cent. of tungsten, and "constantan," which is a cupro-nickel containing 60 per cent. of copper.

The following table by Law[1] gives the resistance in microhms per cubic centimetre, of iron and nickel, together with a number of high resistance alloys used in the electrical industry:—

High Resistance Alloys

Name	Description	Resistance microhms per c.c.
Iron		11.0
Nickel		12.3
Nickel silver	Containing 7 per cent. nickel	18.0
" "	" 10 " " "	21.0
" "	" 20 " " "	29.0
" "	" 30 " " "	40.2
Platinoid		41.0
Tarnac	Cupro-manganese	41.0
Manganin	Copper-nickel-manganese	42 to 48
Nickelin	Copper-nickel	43.0
Ferry	" "	47.2
Constantan	" " (40 per cent. nickel)	50.2
Eureka	" " (similar to Constantan)	50.2
Resistin	Copper-manganese	50.2
Ferrozoid	Nickel-steel	84.0
Kruppin	" " (28 per cent. nickel)	85.0
Vestalin	" " (similar to Kruppin)	85.1
Nickel chrome or nichrome	Nickel-chromium	93.5
Concordin		96.0

The figures given in this table for manganin, nickelin, and resistin, must not be regarded as accurate for all samples known under these names, the composition of the alloys being somewhat variable, as shown by the following analyses collected from various sources:—

Composition of Manganin, Nickelin, Resistin

Alloy	Composition per cent.				
	Copper	Nickel	Manganese	Zinc	Iron
Manganin	84.0	4.0	12.0		
"	82.1	2.3	15.0		0.6
"	58.0	41.0	1.0		
Nickelin	68.0	32.0			
"	55.3	31.1		13.1	
Resistin	86.5		11.7		1.8
"	84.3		13.4		2.0

[1] "Alloys," 2nd Edit., p. 322.

The following table gives a further series of analyses collected from various sources:—

Analyses of Various Alloys Containing Nickel

Alloy	Nickel, per cent.	Copper, per cent.	Zinc, per cent.	Lead, per cent.	Tin, per cent.	Aluminium Iron Chromium Manganese, per cent.
Aluminium-bronze, containing nickel	4.5	85.0	....	....	....	Al 10.5
Aluminium silver	20.0	57.0	20.0	....	....	Al 3.0
Argozoil, for ornamental castings ..	14.0	54.0	28.0	2.0	2.0	....
Copper containing nickel:—						
For driving bands of projectiles..	5.0	95.0	....	....	....	....
Locomotive boiler tubes	3.0	97.0	....	....	....	....
Locomotive firebox stays	2.0	98.0	....	....	....	....
Cupro-nickel for sheet, bullet casings, etc	20.0	80.0	....	....	....	....
Constantan for electrical resistances and thermo-couples	40.0	60.0	....	....	....	....
Nickel Silvers:—						
Firsts	16.0	56.0	28.0	....	....	....
Seconds	14.0	62.0	24.0	....	....	....
Thirds........................	12.0	56.0	32.0	....	....	....
Fourths	10.0	55.0	35.0	....	....	....
Fifths	7.0	57.0	36.0	....	....	....
Finest	34.0	46.0	20.0	....	....	....
Fine white	30.0	50.0	20.0	....	....	....
Good..........................	16.0	56.0	28.0	....	....	....
Low grade.....................	7.0	57.0	36.0	....	....	....
Swiss nickel 20 centime coins (with 15 per cent. of silver)....	10.0	50.0	25.0	....	....	....
Manganin electrical resistance wire	2.3	82.0	....	....	....	Fe 0.6
Nickel-bronze for coinage..........	25.0	75.0	....	....	....	....
Nickel-chrome for thermo-couples..	90.0	....	....	....	....	Cr 10.0
Nickelin electrical resistance wire..	32.0	68.0	....	....	....	....
Plastic bronze bearing metal.......	1.0	64.0	....	30.0	5.0	....
Platinoid electrical resistance wire.	14.0	60.0	24.0	....	....	Mn 1 to 2
Platnam for valve seating..........	58.80	32.55	....	....	12.72	Al 0.32 Fe 0.48
Sterline	17.88	68.52	12.84	0.15	....	Fe 0.76

Special alloys for mixing:—

Alloy	Nickel, per cent.	Silicon, per cent.	Carbon, per cent.	Other Constituents, per cent.
Nickel-tungsten............	25 to 50	0.25 to 0.50	0.5 to 1.0	Tungsten 50 to 75
Nickel-molybdenum........	30 to 50	0.25 to 0.50	0.5 to 1.0	Molybd. 50 to 70
Nickel-chromium	24	0.25	1.0	Chromium 72 to 75
Ferro-nickel silicon (one brand)	30.0	47.2	....	Iron 15.68 Aluminium 2.9 Manganese 0.9 Copper 2.58 Phosphorus 0.02

Alloys for Use in Pyrometers

Increasing attention is being given to the use of nickel as a constituent of alloys to be used as so-called base metal thermo-couples in thermo-electric pyrometers, for the measurement of temperatures which are not sufficiently high to necessitate the use of a platinum and platinum-iridium couple.

This is due not only to the cheapness of base metals as compared with platinum, but also to the fact that properly chosen base metal couples develop a relatively high electro-motive force. Thermo-couples of base metals are in many respects superior to those of platinum for temperatures up to 1000° C., and their use is gradually extending.

Nickel is an important constituent of most of the base metal thermo-couples now in use, including the following:—

Nickel-chromium	and	Nickel-iron-silicon.
Chromium-iron-nickel	and	Aluminium-nickel.
Iron	and	Aluminium-nickel.
Iron	and	Copper-nickel.
Chromium-nickel	and	Iron-nickel.

As a general rule, it may be taken that copper and "constantan" (copper-nickel) couples, and iron and "constantan" couples may be used for temperatures up to about 900° C., giving a very open scale. These couples give a high and very constant electro-motive force, and have the additional advantage of a small co-efficient of resistance.

For temperatures from 700° C to 1000° C., a nickel-chrome (10 per cent. chromium), known as Hoskin alloy, as positive element, in conjunction with an alloy of nickel containing small percentages of various other elements, is most suitable. Such a couple has an electro-motive force about 3.5 times that of platinum at 1100° C.

Pure nickel is also used for thermo-couple leads. To prevent the brittleness that sometimes results in nickel wire used for this purpose, A. L. Marsh[1] has patented a nickel-silicon alloy consisting of nickel with 3 to 5 per cent. of silicon and a trace of aluminium or manganese.

According to O. L. Kowalke,[2] however, silicon is not a desirable constituent in a nickel alloy for thermo-couple material.

Nickel-Copper-Aluminium Alloys

Within recent years, attention has been given to the influence of nickel on certain aluminium alloys. Although the addition of nickel to aluminium produces a series of alloys which have so far proved so be of no practical importance, triple alloys, consisting of copper, nickel and aluminium, which may be regarded as nickel silver in which the zinc is replaced by aluminium, have been used commercially from time to time.

Alloys with upwards of 20 per cent. of nickel, and varying amounts of aluminium, have been introduced under such names as "aluminium silver,"

[1] Brass World, 1913, Vol. IX, p. 388.
[2] Trans. Amer. Electrochem. Soc., 1914, 26, pp. 199-214

"minargent," etc., as substitutes for the finer grades of nickel silver, as they have a beautiful white colour, and take a high polish. Some of these contain up to 7 per cent. of aluminium, but more often are really copper-nickel alloys deoxidized by means of aluminium, only a very small quantity of which remains in the finished metal.[1]

Alloys with 6 to 12 per cent. of aluminium and about 20 to 30 per cent. of nickel were prepared in 1894 by Andrews, who found them hard, fine grained, and of great strength.

More recently, a systematic study of the influence of nickel on some copper-aluminium alloys was undertaken by Read and Greaves,[2] who prepared alloys containing 10 and 5 per cent. of aluminium and varying amounts of nickel (1, 2.5, 7.5, 10, and 15 per cent.), the balance being made up of copper.

Physical Properties and Uses

The alloys were submitted to the usual mechanical tests. When rolled, all the alloys which were tested, (containing from 1 to 15 per cent. nickel), behaved similarly, yielding perfectly sound rods, while the hardness increased with the nickel content.

Wire drawing tests gave sound and smooth wires in every case. Nickel increases the ductility of the 5 per cent. aluminium alloy. The specific gravity is increased by the presence of nickel, while the conductivity is diminished.

The results of corrosion tests seem to indicate that the alloys containing nickel, up to 10 per cent., resist corrosion by sea water and by alkaline solutions better than the pure aluminium-copper alloys, while the latter withstand the action of acids better than those containing nickel. The acids used in the tests were tenth normal sulphuric and hydrochloric acid and vinegar.

The melting points of the alloys ranged from 1042°C. to 1119°C.

The results of a recent investigation by W. B. Parker,[3] on the alloys most suitable for high-speed superheated steam turbine blading clearly indicate that the copper-aluminium-nickel alloys, and the copper-aluminium-manganese alloys. rich in copper, may well repay further investigation for this purpose. Up to the present, the most useful non-ferrous blading alloy appears to be pure phosphor-bronze, Monel metal being used for stationary blades under many conditions. Alloy steels are, however, being chiefly used for want of a better non-ferrous material, in spite of their tendency to rust.

The following analyses are given by Parker[4] as representative of the composition of typical forged commercial copper-aluminium-nickel alloys, and copper-aluminium-manganese alloys:—

[1] J. Inst. Metals, 1914, Vol. XI, p. 169.
[2] Ibid., 1914, Vol. XI, pp. 169-213.
[3] Ibid., 1915, Vol. XIV, pp. 25-69.
[4] l. c., p 55.

Composition of Copper-Aluminium Alloys, with Nickel and Manganese

——	Per cent.	Per cent.	Per cent.
Copper	82.07	79.63	79.0
Aluminium	2.54	9.77	11.5
Nickel	14.64	4.13	5.0
Manganese	nil	0.94	nil
Zinc	0.68	nil	nil
Iron	trace	4.80	4.5
Silicon	0.04	0.14	....

Nickel-Copper Alloys with Chromium and Manganese

The effect of the addition of chromium and of manganese on alloys of the nickel-copper series has been studied by Sebast and Gray,[1] mainly with reference to the electrical resistance and temperature co-efficients. The effect of chromium on pure copper is to slightly increase the resistivity, which indicates that chromium is only very slightly soluble in copper, while on the other hand, the addition of chromium to nickel very greatly increases the resistivity. The form of curve for the nickel-chromium series indicates that nickel is capable of holding chromium in solid solution. The addition of chromium to copper-nickel alloys showed that for any single copper-nickel alloy, the resistivity first rises, and then falls off upon the addition of chromium. At a certain chromium content, a maximum resistivity is obtained for each copper-nickel alloy, and as the concentration of the copper in the alloy increases, this maximum approaches the axis of zero chromium. In all cases, when the resistivity of an alloy is increased by the addition of chromium, the temperature co-efficient is reduced, and conversely.

An alloy of very high resistivity (112 microhms per cm. cube) and a negligible temperature co-efficient (0.000078), which would appear to have good commercial possibilities, was found to have the following composition:—

Copper	15 parts	or 12.5 per cent.
Nickel	85 "	" 70.8 " "
Chromium	20 "	" 16.7 " "

With regard to copper-nickel-manganese alloys, it was found that the addition of manganese causes an increase in resistivity, accompanied by a decrease of temperature co-efficient. The curves indicate that there is an alloy of approximately the following composition which has a resistivity of about 70 microhms per cm. cube, and a temperature co-efficient of zero at 20° C.:—

Copper	55 parts	or 47.8 per cent.
Nickel	45 "	" 39.2 " "
Manganese	15 "	" 13.0 " "

This alloy is stated to be a much better resistor than any of those used at the present time for precision apparatus.

It would appear, from the results so far obtained, that the addition of chromium and of manganese to nickel alloys warrants further investigation.

[1] Washington Meeting Amer. Electrochem. Soc., April 27, 1916 Abstract Met. and Chem. Eng., 1916, Vol. XIV, p. 477.

The British Thomson-Houston Co., Ltd., London, has recently patented a ductile and malleable cobalt-nickel-manganese alloy for use in the manufacture of leading-in wires for electric lamps.[1]

The alloy has a low heat conductivity and is composed of cobalt 20-30 (25), nickel 80-70 (75), and manganese about 2 parts, by weight. It is prepared by melting the cobalt and nickel together in an alundum crucible in an atmosphere of hydrogen, adding the manganese when the melt is quiescent, cooling to about 1250° C., and then chilling the product in water. The materials employed should be free from aluminium, lime and other basic impurities, sulphur, phosphorus, silicon, and carbon, these impurities tending to make the alloy brittle.

Acid-Resisting Alloys

Monel metal and other nickel alloys which show special resistance to corrosion, have already been described.

Attempts made by S. W. Parr[2] to prepare an acid-resisting alloy suitable for casting purposes, resulted in the preparation of a somewhat complex alloy of the following composition:—

Copper	6.42
Manganese	0.98
Silicon	1 04
Tungsten	2.13
Nickel	60.65
Aluminium	1.09
Iron	0.76
Chromium	21 07
Molybdenum	4.67
Total	98.81

Carbon and boron not determined.

The alloy is called "Illium". Its melting point is approximately 1300° C. and the furnace must be capable of readily attaining the temperature of molten nickel, say 1600 degrees. When thoroughly liquid, the alloy pours readily and fills the mould perfectly, but the freezing point is so quickly reached that feeding of the casting from risers, to make up for shrinkage, is practically impossible. Moreover, the shrinkage is so excessive that cracks and hollow spots are very difficult to avoid. The alloy works about the same as tool steel.

Attempts to draw the alloy into wire and roll it into sheets have been only partially successful, but are said to indicate the likelihood of success when the conditions for proper annealing are better understood. The tensile strength of the cast metal is approximately 50,000 lbs. per sq. inch.

The unit of reference for measuring the amount of corrosion was as follows:— A standard disc of the alloy was prepared, having ten square centimetres of surface. This was submerged for a given length of time, usually 24 hrs., in nitric acid of approximately 25 per cent. HNO_3. The loss in weight was calculated to the amount which would be represented for an area of 100 sq. centimetres per hour. In one test on a small casting, the loss in weight was 0.03 mg. In the last seven

[1] J. Soc. Chem. Ind., 1916, Vol. 35, p. 695.
[2] Amer. Inst. Metals, 1916.

castings weighing about 10 lbs. each, six out of the seven standard discs did not show a weighable loss after 24 hours' contact with the nitric acid.

It is stated that the addition of 5 to 10 per cent. of tantalum considerably increases the acid-resisting property of nickel. An alloy containing 30 per cent. of tantalum has been patented by Siemens and Halske.[1] It is non-magnetic, can be easily rolled, forged, and drawn, and is equal to steel in elasticity and tensile strength. It is not attacked by boiling aqua regia or other acids, and is not oxidized when heated in the air, but may become brittle when very strongly heated.

Nickel Alloys with Tungsten and Lead

For a series of tests to determine the influence of tungsten on nickel, R. Irmann[2] prepared an alloy of nickel with 47 per cent. tungsten in an electric crucible furnace from almost chemically pure tungsten and cube nickel containing sulphur 0.019, manganese 0.028, zinc 0.048, and copper 0.107 per cent. This alloy was used in the preparation of other alloys with less tungsten. The equilibrium diagram shows two maxima, at 6 and 14.3 per cent. (atomic) tungsten respectively; the former would correspond to the compound $Ni_{16}W$, the latter to the compound Ni_6W. The alloys with these compositions exhibit also maximum resistance to acid corrosion, a minimum occurring in the neighbourhood of a eutectic composition. Nickel possesses a considerable resistance to attack by 65 per cent. acid, and it is increased four-fold by the addition of 5 per cent. tungsten and twelve-fold by the addition of 10 per cent. From 10 to 18 per cent. tungsten the resistance increases more slowly, and at about 25 per cent. diminishes considerably, increasing again from 30 per cent. The electrical resistance increases almost proportionally to the tungsten content, up to 23 per cent. tungsten. The tensile strength diminishes rapidly with increasing tungsten content, attaining a minimum with 25 per cent., and then rises again just as rapidly. The ductility of nickel is, however, adversely affected by the addition of tungsten, and it is possible to form into sheets only those alloys with under about 18 per cent. of that metal.

Various lead-nickel alloys have been tested by A. M. Fairlie[3] to determine their relative strength, ductility, and acid-resisting properties as compared with lead-antimony alloys of similar composition.

The strongest lead-antimony alloy was found to be that containing 90 per cent. lead and 10 per cent. antimony; and its acid-resisting qualities are almost equal to those of any other alloys of the lead-antimony series.

The lead-nickel alloys were found to possess superior acid-resisting properties, as compared with the lead-antimony alloys, but showed a tensile strength less than one-half that of the best lead-antimony alloys.

During the past few years, investigations have been carried out to determine the effects of small quantities of nickel on some well-known commercial alloys.

Thus, it was found that Muntz metal rolled better when made from copper containing 0.3 per cent. of nickel, than when made from a number of the best brands of refined copper.

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[1] Ger. Pat. 277,242, March 4, 1913.
[2] Metall u. Erz, 1915, 12, 358-364. Z angew. Chem, 1916, 29, Ref., 12-13.
[3] Metal Industry, 1911, Vol. III, p. 64.

A microscopical study of the alloys of copper-zinc-nickel, by L. Guillet[1] shows that the coefficient of equivalence of nickel when added to copper-zinc alloys is 1.2, that is, its presence diminishes the apparent proportion of zinc in that ratio.

According to him,[2] nickel is the most efficient of the metals yet examined, in raising the "imaginary percentage" of copper in brass, i.e., a brass containing a certain percentage of nickel, in addition to copper and zinc, is similar in mechanical properties to an ordinary brass of higher copper content than would be the case if the nickel were replaced by another metal. Other things being equal, the addition of a small percentage of nickel makes a brass easier to work cold. Tables are given showing the improvement in the mechanical properties of brasses effected by the presence of nickel up to 10 per cent.

The brass sheets issued by the United States Bureau of Standards, Washington, as an analytical standard, contains 0.5 per cent. of nickel.[3]

Nickel is sometimes added to manganese bronze to the extent of about 2 per cent., and to aluminium bronze to the extent of about 5 per cent.

A plastic bronze used on many railways for heavy bearings consists of copper 64 per cent., lead 30 per cent., tin 5 per cent., and nickel 1 per cent.

As cobalt is a common associate of nickel, it is not surprising to find that the alloys of the nickel-cobalt series have been the subject of investigation. The cast alloys have been examined by R. Ruer and K. Kaneko[4] with a view to determining their resistance. The maximum resistance and minimum conductivity were found to occur at about 17 per cent. of cobalt, the curve being very steep on the nickel side and practically linear on the cobalt side.

The hardness by Brinell's test, on the cast metal, is very irregular in the cast condition, but becomes uniform after heating to 1150° C. The hardness curve has then a peculiar form, being nearly horizontal from 0 to 60 per cent. of cobalt, then rising very steeply and passing through a maximum at 92 per cent. of cobalt. The same discontinuity at about 70 per cent. was observed by these authors in the magnetic properties and in the micrographic structure, the lamellar twinning of the polygonal grains only being observed from 70 per cent. upwards.

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[1] Comptes Rendus, 1912, Vol. CLV. J. Inst. Met., 1913, Vol. IX, p. 213.
[2] Rev. Met., 1913, 10, 1130-1141.
[3] Met. & Chem. Eng., 1914, Vol. XII, p. 80. Abstract per Journ. Inst. Met., 1914, Vol. XI, p. 308.
[4] Ferrum, 1913, Vol. X., p. 257. Abst. Journ. Inst. Metals, 1913, Vol. X, p. 407.

CHAPTER VII

Nickel Steel and Other Nickel Alloys Containing Iron

A very large amount of metallographic and physical testing work has been done and published in connection with nickel steels and, although the conclusions to be drawn therefrom are of more importance in connection with this Report than the actual details, it has been thought desirable to include a description of certain portions of the work together with a reference to publications where fuller details can be obtained. The Commission visited and received information from a large number of steel makers and users and technologists in Great Britain and the United States, and is indebted to Mr. G. C. Lloyd, the Secretary of the Iron and Steel Institute of London, for a large amount of information. This was presented in the form of an independent technical section but, with his permission, has been incorporated with other matter important to the non-technical reader, but naturally omitted from a scientific summary.

So far as possible, the portions of this section which deal with the work of the metallographers and include a host of special terms well known to those experienced in work upon alloys but less intelligible to the layman, have been kept together, but the necessity for transferring portions elsewhere and inserting much extraneous matter among the purely technical matter, has prevented this intention being fully carried out. The Commissioners also feel that the highly technical nature of the nickel-steel industry, the variety of alloys comprised under the term "nickel steel," the extension of their use, the frequent additions to their number, the change in their relative importance, and their general interest to the specialist, justify the inclusion, in this section, of matter of a type which has not been given in any other part of the Report.

It should be specially remembered that the term nickel steel when used generally, includes nickel-chromium steel, and often covers special steels containing other metals as an essential constituent.

The general history of the nickel industry has been dealt with already, particularly in Chapter IV, and some additional details have been given in Chapter VI dealing with the Non-ferrous Alloys of Nickel.

Bibliography of Nickel Steel

Further particulars will be found in the following publications, some of which are ordinary papers read before technical societies, etc., while others are separate works dealing wholly or mainly with nickel steel:—

1. "Alloys of Iron and Nickel," by R. A. Hadfield, Proc. Inst. of Civil Eng. Vol. CXXXVIII, Session 1898-99. Part IV. 169 pages.

2. "Nickel-Steel: A Synopsis of Experiment and Opinion," by D. H. Browne. California Meeting, Sept., 1899, Trans. Amer. Inst. of Min. Eng. 77 pages.

3. "Alloys of Iron and Nickel," by F. Osmond. Proc. Inst. of Civil Eng. Vol CXXXVIII, Session 1898-99. Part IV. 18 pages.

4. "Manufacture and Uses of Alloy Steels," by H. D. Hibbard, U. S. Bureau of Mines. 72 pages.

5. "Invar and Related Nickel Steels," Circular of the U. S. Bureau of Standards, No. 58. 68 pages.
6. "Nickel Steel: Its Properties and Applications," by A. L. Colby, Proc. Amer. Society for Testing Materials, Vol. III, 1903. 29 pages.
7. "A Comparison of Certain Physical Properties of Nickel Steel and Carbon Steel, proving the Superiority of Nickel Steel over Carbon Steel, for Bridge and Structural Purposes," by A. L. Colby, July, 1903. 103 pages
8. "Alloy Steels in Bridgework," by J. A. L. Waddell, delivered before the International Engineering Congress at San Francisco, September, 1915. 41 pages.
9. "Crucible Chrome-Nickel Steel: Its Manufacture and Properties," The Carpenter Steel Company, Reading, Pa., U S.A. 23 pages.
10. "The Special Steels in Theory and Practice," by W. Giesen. Carnegie Scholarship Memoirs, Iron and Steel Institute, London, No. 1, for 1909.
11. "Les Applications des Aciers au Nickel," avec un appendice sur la Théorie des Aciers au Nickel, par Ch.-Ed. Guillaume. 212 pages.
12. "Les Aciers au Nickel et Leurs Applications à L'Horlogerie," par Ch.-Ed. Guillaume. 54 pages.
13. "Mayari Steel," the Pennsylvania Steel Company, Steelton, Pa. 87 pages.
14. "The Use of Mayari Iron in Foundry Mixtures," the Pennsylvania Steel Company, Steelton, Pa., U.S.A. 21 pages.
15. "A Method of Producing High-Class Steel from Pig Iron Containing Chromium, Nickel, and Cobalt," by A. W. Richards. Iron and Steel Inst. 8 pages.
16. "The Chemical and Mechanical Relations of Iron, Tungsten, and Carbon, and of Iron, Nickel, and Carbon," by Prof. J. O. Arnold, and Prof. A. A. Read. Proc. Inst. Mech. Eng., Mar. 20, 1914. Pages 223-279.
17. "The Magnetic Properties of Manganese and Nickel Steels," by S. Hilpert, and W. Mathesius. Journ. Iron and Steel Inst., No. II, for 1912. Pages 302-310.
18. "Some Properties of Heat-treated Three Per Cent. Nickel Steels," by A. McWilliam, and E. J. Barnes. Journ. Iron and Steel Inst., No. 1, for 1911. Pages 269-293.
19. "The Magnetic Properties of Some Nickel Steels," with some notes on the Structures of Meteoric Iron, by E. Colver-Glauert and S. Hilpert. Journ. Iron and Steel Inst., No. I, for 1911. Pages 375-411.
20. "The Thermal-Magnetic Transformations of 25 per cent. Nickel Steel," by E. Colver-Glauert, and S. Hilpert. Journ. Iron and Steel Inst., No. II, for 1912. Pages 295-301.
21. "Influence of Some Elements on the Mechanical Properties of Steel," by Dr. J. E. Stead. Iron and Steel Inst., Sept. 21-22, 1916. 86 pages.

The following may be consulted regarding the standard specifications imposed by special authorities for steels containing nickel. They are of interest, not only in connection with the preparation of the test pieces and with the tests to be passed, but on account of the stated percentages of nickel and other metals present in standard types of steel, and are quoted very fully later in this section.

22. "British Standard Specifications for Wrought Steels for Automobiles," Report No. 75. The Engineering Standards Committee, May, 1916.
23 "Structural Nickel Steel," Standard Specifications adopted by the Amer. Soc. for Testing Materials, 1912.
24. "Standard Specifications of the Society of Automobile Engineers," Vol. 8, Part 2, 1913.

Early Experimenters with Nickel Steel

Among the above-quoted papers, the first four are of special interest as, in addition to dealing with the alloys of nickel with iron, each contains much of interest in connection with other uses of nickel and with its history and each contains a general bibliography of the metal.

Nickel steel, including nickel-chromium steel, stands chronologically as the fourth alloy steel and, in 1913 nickel was an essential constituent of over 180,000 tons of steel, made in the United States, of which slightly over one-third was simple nickel steel. A search through early patent records or literature does not indicate, however, that much interest was taken in nickel steel until, in 1889,

James Riley, of Glasgow,[1] published his paper on the general properties of steels, containing from low percentages up to nearly 50 per cent. of nickel, as prepared for him by Marbeau in France.

It is true that the resistance of meteoric iron[2] to corrosion was well known, and that nickel had been found in some of the old steels which were known to be of superior quality, but such authorities as Percy writing, even after the middle of the 19th century, dismiss the alloy in a few lines. It is probable that the work done in the early days covered a much larger field than is apparent from the published results, because what was published referred largely to alloys containing amounts of nickel approximating to that now commonly used in ordinary nickel-steels, and the properties described are those of the most practical interest. This is shown in the following early British patents where, although the claims are vague and indicate that the inventors were almost groping in the dark, the references to non-oxidizability, etc., and to the use of chromium, manganese and copper indicate to the enthusiastic historian that the investigators possessed an almost prophetic instinct or published only a small part of the information they possessed:—

1. Hickling, S. S. (February 28, 1799—No. 2296), makes hollow vessels of cast iron alloyed with nickel—from "40 to 4 parts of iron, with 1 part of nickel." He states that such vessels may be lined with copper by the "precipitation" process.
2. John Martineau, the younger, and H. W. Smith (Oct. 6, 1825, No. 5259) produce steel of improved quality, and presenting the wavy appearance of Damascus swords, by melting with the metal various substances, including nickel, zinc and "chromate of iron." The latter, no doubt, referred to the mineral chromite or to the artificial double oxide of chromium and iron.
3. Alexander Parkes (Oct. 29, 1844, No. 10366) patents a "useful alloy" of nickel, iron and copper, and later (Sept. 11, 1851, No. 13746) a "useful alloy" of nickel, iron and chromium and another of nickel, copper and chromium.
4. M. Poole (Nov. 27, 1845, No 10,971) claims that, to hinder the oxidation of cast iron, steel and malleable iron, and render malleable iron more hard and durable, from 2 to 10 per cent. of copper, tin, nickel, or antimony, may be mixed with cast iron or steel, while molten.
5. Thos. Weatherburn Dodds (March 7, 1853, No. 571). To produce non-oxidizable steel, the metal is treated in a crucible with from one-twenty-fifth to four-twenty-fifths of "nickel, German silver or Argentine," sometimes with addition of manganese.

We find, also, in Aikin's "Dictionary of Chemistry and Mineralogy," 1807, Vol. 2, on page 138, the statement that meteoric iron is "scarcely at all oxydable by exposure to the weather." He adds "it is highly probable therefore that nickel may become a metal of vast importance if its power of protecting iron from rust be fully established."

Percy[3] states that Faraday and Stoddard[4] made alloys with horseshoe nails and 3 per cent. of nickel. The alloy, it is stated, "was quite as malleable and pleasant to work under the hammer as pure iron. When polished, it was rather whiter than iron. Its specific gravity was 7.804, and that of the hammered alloy of steel with 3 per cent. of nickel was 7.750." He gives the results of certain of his own experiments on steels containing other percentages of nickel, and mentions that Berthier ascribes exactly the same characteristics to the alloys of iron and cobalt as to those of iron with nickel. He states that it is doubtful whether sufficient experiments had

[1] J. Iron and Steel Inst., 1889, Vol. I, p. 45.
[2] See a very complete paper (44 pages) on the Use of Meteoric Iron by Primitive Man, by G. F. Zimmer, read in September, 1916, before the London Iron and Steel Institute.
[3] Metallurgy, Iron and Steel, 1864.
[4] The Quarterly Journal of Science, Literature and the Arts, Vol. IX, 1820, p. 324.

been made to justify such a general conclusion, but does not state that he has any reason to doubt it.

Properties of Nickel Steel

The commercial grades of nickel steel are those containing from 2 to 5 per cent. of nickel either alone or in conjunction with another metal or metals, or those in which high proportions of nickel even up to 95 per cent. of nickel to 5 per cent. of iron, are used. The useful nickel steels may be said to range from 2 to nearly 50 per cent., i.e., more than the range for any other metal used in steelmaking, and the term, as already stated, commonly covers nickel-chromium steels and many complex steels containing nickel with such rare elements as vanadium, etc.

Broadly speaking, it may be stated that simple nickel steels contain 3 to 4 per cent. of nickel and low carbon, and are commonly produced in the open hearth. The nickel may be present in the original ore—as in the case of steel made direct from nickel ores or nickeliferous iron ores, such as the Cuban ore and others, as described at the end of this section, or may be added at any stage of the smelting or casting. It may even be added in the form of oxide, as nickel oxide is reduced by metallic iron, but that practice, although formerly carried on to a slight extent, has been entirely abandoned. Nickel is used only as an alloying metal, and is in no sense a purifying agent, as is the case with manganese, aluminium and certain other elements largely used in steelmaking.

The tensile strength and elastic limit of nickel-iron alloys and nickel steels (0.06—0.1 per cent. C.) increase with the nickel to a maximum at about 20 per cent. Beyond this they recede, elongation increasing abnormally up to about 30 per cent. The ratio of elastic limit to tensile strength increases with the nickel slowly up to about 10 per cent., where there is a sharp rise, and continues gradually up to 20 per cent., after which the ratio falls rapidly.

With steels containing between 10 and 20 per cent. of nickel, neither quenching nor annealing has any decided effect. Above 20 per cent., quenching softens the steel (markedly at 30 per cent.), lowering both the tensile strength and elastic limit and increasing the elongation, but not affecting the cutting properties at low speed.

Nickel tends to check segregation, probably by raising the melting point of the carbides and causing more uniform setting, finer grain being produced. It does not prevent blowholes. In medium and high carbon steels, the nickel seems to cause a more intimate combination between the iron and carbon, a double nickel-iron carbide being probably formed, and the matrix hardened.

Below 1 per cent. of nickel, the welding of steel is not affected, and even up to 3 per cent. good results can be obtained with care. The tenacity of the film of oxide causes difficulty as the nickel increases.

Effects of Carbon and Manganese

The mechanical properties of nickel steels are dependent not alone on the nickel content and the heat treatment, etc., which they have received; but small amounts of other elements usually found in steels, such as carbon and manganese,

affect the properties appreciably. This may readily be seen when nickel steels are divided into groups according to their mechanical properties or their metallographic structures and depending on the carbon and nickel contents. Guillet gives the following division:—

Per cent. Carbon.	Per cent. Nickel.		
	Group 1.	Group 2	Group 3.
0.12	0–10	10–27	plus 27
0.25	0–7	7–25	" 25
0.80	0–5	5–15	" 15

The properties of the first group are similar to those of carbon steels with the strength and hardness slightly increased by the nickel.

The alloys of the second group have about the same properties as quenched high-carbon steels, having high tensile strength and elastic limit and low elongations.

The third group, including invar, have a medium breaking strength and low elastic limit, and are very ductile, though difficult to forge.

In his discussion of the properties of nickel steels, Giesen[1] has a similar division, but gives slightly higher percentages of nickel as the limits of each group, i.e., (1) 2.5 to 35, (2) 2 to 28.3, and (3) 2.1 to 29.3.

Quoting from D. H. Browne,[2]

> The colour of the finished steel becomes lighter with the increase in the nickel-contents. The ordinary 3.5 per cent. nickel steels do not perceptibly differ in appearance from simple steels; at 10 per cent. of nickel, the colour is noticeably lighter; and, at 18 per cent., the steel has a soft silvery whiteness; with high percentages the colour seems again to darken, and the 25 and 30 per cent. nickel steels are duller and less lustrous than the 18 per cent. In texture, moreover, the 18 per cent. nickel-steels appear more smooth and close-grained than iron alloys containing a larger percentage of nickel. . . .

The following notes have been mainly taken from the transactions of the International Engineering Congress[3]:—

Although nickel alloys with steel in all proportions, by far the most important nickel steel, from an engineering standpoint, apart, of course, from nickel-chromium steel, is the low—and medium—carbon steel with 3 to 4 per cent. of nickel, commonly known as 3½ per cent. nickel steel. The presence of manganese in nickel steel is very essential, as it has a marked effect on the mechanical properties. The amount of manganese should range from 0.50 to 0.80 per cent. This steel has been extensively used since its introduction in 1889, and is a good all-round engineering and structural steel with considerably higher elastic limit and tensile strength than the corresponding carbon steel, and with practically the same degree of ductility. The low-carbon steel, 0.10 per cent. to 0.20 per cent. carbon, is

[1] Carnegie Scholarship Memoir of the Iron and Steel Institute, London, 1909, p. 24.
[2] Nickel Steel, A Synopsis of Experiment and Opinion, p. 31.
[3] 1915, p. 29 to 31.

used extensively for case-hardening parts. It case-hardens more readily than carbon steel, and gives a harder casing with a strong, tough, fibrous core. A great deal of nickel steel with carbon from 0.20 to 0.35 per cent. has been used in shapes and plates as rolled, and in annealed eye-bars for bridge construction. In this condition, which is not to be recommended for forgings, the following are typical physical propertes:—

Elastic limit, lbs. per sq. in.	45,000 to 60,000
Tensile strength, lbs. per sq. in.	80,000 to 100,000
Elongation in 2 inches	20 to 15 per cent.
Reduction of area	40 to 25 per cent.

Annealed nickel steel forgings have only slight advantage in strength over carbon steel, and consequently are not advantageous, either from an engineering standpoint or commercially, unless heat-treated. With heat-treatment, the nickel steel gives considerably higher strength than carbon steel, combined with greater ductility or toughness. It does not give as high values as the nickel-chromium and chromium vanadium steels. Nickel steel rolls and forges readily, and machines easily. It developes a very thick, hard scale which is apt to give considerable trouble in drop-forging, and is hard on the dies. Nickel steel is also very liable to develop seaminess, especially when made in large heats and cast into large ingots, as is now customary. It requires a larger discard to ensure soundness. The use of nickel steel in forgings, and particularly drop-forgings, is falling off in favour of other alloy steels with greater values.

Effects of Chromium

The addition of chromium to nickel steel has a marked effect, greatly increasing the strength and resistance to shock, and particularly the hardness. It is more difficult to forge and heat-treat and harder to machine, and is also liable to the seaminess frequently present in nickel steel. There are three types of this steel, differing both in the percentage of nickel and chromium, and all with low or medium carbon:—

——	Nickel.	Chromium.	Carbon
	per cent.	per cent.	per cent.
1st	3.5	1.50	0.25 to 0.45
2nd	2.0	1.00	0.10 to 0.45
3rd	1.5	0.50	0.10 to 0.45

The first type is used principally for armour-plate and armour-piercing projectiles and came into use about 1895, superseding the nickel plates and chromium projectiles. The other two types were developed by the automobile industry. The second type is used largely for automobile forgings. It gives high strength with heat-treatment, has great hardness and good shock- and fatigue-resisting qualities. The third type is a largely-used, all-round engineering steel. It is used for automobile forgings, and for a variety of miscellaneous drop-forgings

and machine parts. It is an excellent case-hardening steel, carbonizing readily. This type is more tractable in working, heat-treating and machining than the other two. It is also somewhat lower in tensile strength.

To show the principal types in use of nickel steels and of nickel-chromium and other steels containing nickel, their composition, the properties which they commonly possess, and the tests which they are required to pass to satisfy the principal requirements of the trade, the following particulars are quoted from current official specifications and elsewhere:—

Comparison of Nickel, Nickel-Copper and Other Alloy Steels with Ordinary Steels, Etc., Compiled from Various Sources.

	Elastic Limit lbs. per sq. in.	Tensile Strength. lbs. per sq. in.	Elongation in 2 in. per cent. of area	Reduction of area. Per cent
Specification of:—				
1. Am. Soc. for Testing Materials. 3½ p.c. nickel steel	55,000	95,000 to 110,000	16	25
2. U. S. Navy (high grade). 3½ p.c. nickel steel. (Toughened)	65,000	95,000	25	....
3. U. S. Navy (Class A). 3½ p.c. nickel steel. (Natural)	50,000	80,000	25	....
4. Auto steel, shafts, bolts, etc. (Natural)	70,000	100,000	16	....
5. Government specifications for carbon steel castings. (Medium)	31,000	70,000	18.0	25.0
6. Government specifications for carbon steel forgings. (Annealed)	40,000	80,000	22.0	35.0
7. Government specifications for carbon steel forgings. (Oil tempered)	55,000	90,000	20.0	45.0
8. Government specifications for nickel steel forgings. (Annealed)	50,000	80,000	25.0	45.0
9. Government specifications for nickel steel forgings. (Oil tempered)	65,000	95,000	21.0	50.0
Tests on:—				
10. Carbon steel (Annealed)	51,440	109,500	19.5	30.31
11. Nickel steel. 3½ p.c. nickel. (Annealed)	66,720	100,330	25.0	54.5
12. Carbon steel. (Oil tempered)	67,230	129,360	17.5	38.53
13. Nickel steel. 3½ p.c. nickel. (Oil tempered)	76,390	103,890	25.0	61.56
14. Nickel steel, 4.57 p.c. Ni. 0.30 p.c. carbon, for rifle barrels at Bethlehem Steel Works	80,000	100,000	....	....
Nickel Copper Steels:—				
15. Ni. 2.8 p.c., Cu. 1.2 p.c., C. 0.11 p.c.	66,300	83,600	26.5	65.4
16. Ni. 2.8 p.c., Cu. 1.2 p.c., C. 0.61 p.c.	120,000	151,000	8.0	15.8
17. Ni. 2.1 p.c., Cu. 0.90 p.c., C. 0.10 p.c.	64,600	75,300	25.5	71.4
18. Ni. 1.4 p.c., Cu. 0.60 p.c., C. 0.15 p.c.	63,700	75,500	28.0	65.4
19. Open hearth nickel steel. Ni. 3.36 p.c., C. 0.46 p.c., Si. .066 p.c., Mn. .70 p.c., P. .021 p.c., S. .034 p.c. (Rolled natural)	74,625	122,000	16.0	34.0
20. Open hearth nickel steel, as above. (Annealed)	64,750	119,000	17.0	37.5
21. Open hearth nickel steel, as above. (Heated to 1500° F. quenched in oil and drawn back to 800°. F. and kept in that condition)	154,500	175,000	9.75	30.8
22. Open hearth nickel steel. (Same as 19.) (Heated and quenched at 1500° F. and drawn back to 600° F.)	185,000	200,000	2.0	4.0
23. Nickel-copper steel. Ni. 3.62 p.c., Cu. 0.48 p.c., C. 0.44 p.c., Si. 0.034 p.c., Mn. 0.50 p.c., P. 0.013 p.c., S. 0.013 p.c. (Rolled natural)	72,400	115,000	22.0	51.0

Comparison of Nickel, Nickel-Copper and Other Alloy Steels with Ordinary Steels, Etc, Compiled from Various Sources.—Continued.

	Elastic Limit. lbs. per sq. in.	Tensile Strength. lbs. per sq. in.	Elongation in 2 in. per cent. of area	Reduction of area. Per cent.
24. As above. (Annealed)	63,750	107,300	25.0	48.0
25. As above. (Heated and drawn same as 21)	154,000	172,500	13.25	49.1
26. As above. (Heated and quenched at 1500° F. and drawn back to 600° F)	185,000	200,000	12.0	46.0
27. Nickel-copper steel from Sudbury ore Ni. 2.51 p c., Cu 1 07 p.c., Mn. 0 83 p.c., C 0 51 p c., S 0.034 p.c.	77,650	116,000	18.0	32.5
28. Nickel-copper steel from Sudbury ore Ni. 1.84 p c., Cu. 0.65 p.c., Mn. 0.70 p.c., S. 0.048 p.c., C. 0.48 p.c.	60,850	94,360	23.0	43.0
29. Nickel-copper steel from Sudbury slag. Ni. 1.06 p c., Cu. 0 40 p.c., Mn. 0.66 p c., S. 0 046 p c., C. 0 51 p.c.	54,000	87,800	21.0	34.0
30. Monel metal rolled plates	45,000	90,000	30.0	60.0
31. Monel metal rolled rods	50,000	100,000	30.0	50.0
32. Soft steel-rolled plates	30,000	60,000	35.0	35.0
33. Copper rolled plates. (Natural)	18,000	34,000	52.0	57.0

Notes. 11 to 14 are quoted from Colby.
15 to 18 " " " Clamer.
19 to 26 " " " Mathews.
30 to 33 " " " D. H. Browne.
27 to 29 " " " Olson.

British Standard Specifications for Automobile Steels

The British Standard Specifications for Wrought Steels for Automobiles, Report No. 75, issued May, 1916, by the Engineering Standards Committee, are as follows:—

E.S.C. 2 Per Cent Nickel Case-Hardening Steel

The class of steel specified below shall be referred to as E.S.C. 2 per cent. Nickel Case-hardening Steel:—

Carbon	0.10 to 0.15 per cent.
Silicon	not over 0.30 "
Manganese	0.25 to 0.50 "
Sulphur	not over 0.05 "
Phosphorus	" 0.05 "
Nickel	2.00 to 2.50 "

When normalized at 850°C. to 900°C., this steel shall pass in every particular the following check test:—

Tensile Breaking Strength	25 to 35 tons per sq. inch.
Yield Ratio	not less than 55 per cent.
Elongation	" " 30 "
Reduction of Area	" " 55 "

The Brinell hardness number corresponding to the above should be approximately 103 to 153.

E.S.C. 5 PER CENT. NICKEL CASE-HARDENING STEEL

The class of steel specified below shall be referred to as E.S.C. 5 per cent. Nickel Case-hardening Steel:—

Carbon	not over 0.15 per cent
Silicon	" 0.20 "
Manganese	" 0.40 "
Sulphur	" 0.05 "
Phosphorus	" 0.05 "
Nickel	4.75 to 5.75 "

When normalized at 820°C. to 860°C., this steel shall pass in every particular the following check test:—

Tensile Breaking Strength	25 to 40 tons per sq. inch.
Yield Ratio	not less than 60 per cent.
Elongation	" " 30 "
Reduction of Area	" " 55 "

The Brinell hardness number corresponding to the above should be approximately 103 to 179.

E.S.C. 3 PER CENT. NICKEL STEEL

The class of steel specified below shall be referred to as E.S.C. 3 per cent. Nickel Steel:—

Carbon	0.25 to 0.35 per cent.
Silicon	not over 0.30 "
Manganese	0.35 to 0.75 "
Sulphur	not over 0.04 "
Phosphorus	" 0.04 "
Nickel	2.75 to 3.50 "

When normalized at 840°C. to 880°C., this steel shall pass in every particular the following check test:—

Tensile Breaking Strength	35 to 45 tons per sq. inch.
Yield Ratio	not less than 55 per cent.
Elongation	" " 24 "
Reduction of Area	" " 45 "

The Brinell hardness number corresponding to the above should be approximately 140 to 202.

E.S.C. 1½ PER CENT. NICKEL-CHROME STEEL

The class of steel specified below shall be referred to as E.S.C. 1½ per cent. Nickel-Chrome Steel:—

Carbon	0.25 to 0.35 per cent.
Silicon	not over 0.30 "
Manganese	0.35 to 0.60 "
Sulphur	not over 0.04 "
Phosphorus	" 0.04 "
Nickel	1.25 to 1.75 "
Chromium	0.75 to 1.25 "

When oil-hardened from 850°C. and tempered at 600°C., this steel shall pass in every particular the following check test:—

Tensile Breaking Strength	not less than 45 tons per sq. inch.
Yield Ratio	not less than 70 per cent.
Elongation	" " 15 "
Reduction of Area	" " 50 "

The Brinell hardness number corresponding to the above should be approximately 179.

E S.C. 3 PER CENT. NICKEL-CHROME STEEL

The class of steel specified below shall be referred to as E.S.C. 3 per cent. Nickel-Chrome Steel:—

Carbon	0.20 to 0.30 per cent.
Silicon	not over 0.30 "
Manganese	0.35 to 0.60 "
Sulphur	not over 0.04 "
Phosphorus	" 0.04 "
Nickel	2.75 to 3.50 "
Chromium	0.45 to 0.75 "

When oil-hardened from 820°C. and tempered at 600°C., this steel shall pass in every particular the following check test:—

Tensile Breaking Strength	not less than 45 tons per sq. inch.
Yield Ratio	not less than 75 per cent.
Elongation	" " 15 "
Reduction of Area	" " 50 "

The Brinell hardness number corresponding to the above should be approximately 179.

E S.C. AIR-HARDENING NICKEL-CHROME STEEL

The class of steel specified below shall be referred to as E.S.C. Air-Hardening Nickel-Chrome Steel:—

Carbon	0.28 to 0.36 per cent.
Silicon	not over 0.30 "
Manganese	0.35 to 0.60 "
Sulphur	not over 0.04 "
Phosphorus	" 0.04 "
Nickel	3.50 to 4.50 "
Chromium	1.25 to 1.75 "

A test bar of this steel that has been air-hardened from 820°C. shall pass in every particular the following check test:—

Tensile Breaking Strength	not less than 100 tons per sq inch.
Yield Ratio	not less than 75 per cent.
Elongation	" " 5 "
Reduction of Area	" " 13 "

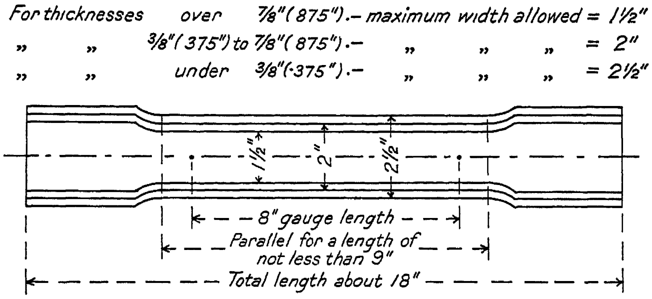
The Brinell hardness number corresponding to the above should be approximately 418.

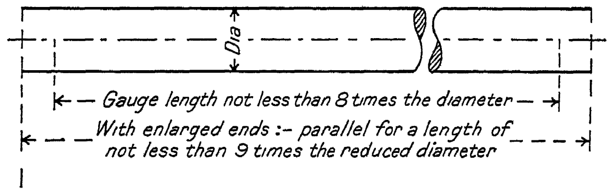
The tensile piece before being air-hardened shall have its parallel portion machined to within .02 inch of the finished diameter of the test piece and this portion shall, after the test piece has been hardened, be reduced to the required diameter by grinding.

Particulars of Test Pieces

The following are particulars and drawings of the test pieces to be used for the tests:—

Test Piece A.—The widths of the test pieces for plates were selected to comply with the two following conditions: (1) As the great bulk of plates to be tested are from 3/8 to 7/8 inch thick, it was desirable for the sake of convenience that the test pieces for such plates should be of uniform width and, in accordance with very general practice, a width of 2 inches was selected. (2) With a test piece of a given form, the percentage of elongation was found to be less for thick plates than for thin ones; with steel of the same quality in other respects it was desirable therefore to choose widths of test piece which would be slightly in favour of the thicker plates. This is secured with the widths selected for the Standard Test Piece of form A.

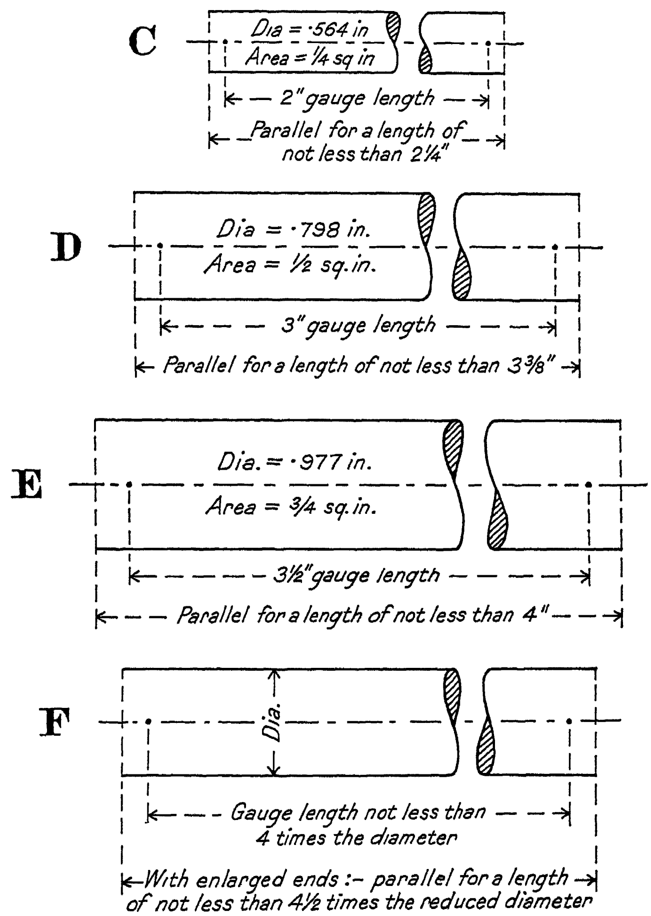




Test Piece B.—All test pieces of form B are strictly similar, and for the same material give the same percentage of elongation. They are nearly similar to a test piece of form A, 8 inches in gauge length, 2 inches wide, and 3/8 inch thick.

Test Pieces C, D, E.—These were arranged to meet the very common practice of making test pieces for forgings, axles, tyres, etc., of either 1/4 sq. in. or 1/2 sq. in. in sectional area. With the gauge lengths decided upon, these three forms are very nearly similar, and, for a given material, give very approximately the same percentage of elongation. Though not exactly, they are approximately similar to the Standard Test Piece F, and for the same material give a nearly identical, but slightly greater, percentage of elongation.

Test Piece F (for test pieces over 1 inch diameter).—In some testing machines it was found inconvenient to use form B for bars of over 1 inch in diameter, and form F of half the gauge length is designed to meet such cases. For a given material the percentage of elongation with Test Piece F is greater than with Test Piece B, and this difference is provided for in the British Standard Specifications.



Form of Ends.—In the case of the round Test Pieces B, C, D, E and F, the form of the ends is to be as required in order to suit the various methods employed for gripping the test piece. When enlarged ends are used, the length of the parallel portion of the test piece must in no case be less than that noted on the diagrams.

American Specifications for Structural Nickel Steel

The American Society for Testing Materials (affiliated with the International Association for Testing Materials) adopted the following Standard Specifications, in 1912.

1. MANUFACTURE

1. The steel shall be made by the open-hearth process.

2. A discard of at least 25 per cent. shall be made from the top of each ingot intended for eye bars. If necessary, the shearing shall be continued until sound metal is found.

2. CHEMICAL PROPERTIES AND TESTS

3. The steel shall conform to the following requirements as to chemical composition:—

Chemical Composition

Elements Considered.	Rivets.	Plates and Shapes.	Bars and Rollers Unannealed.	Bars and Pins Annealed.
Carbon, max. per cent..................	0.30	0.45	0.45	0.45
Manganese, max. per cent	0.60	0.70	0.70	0.70
Phosphorus, max. per cent..... (Acid....	0.04	0.05	0.05	0.05
(Basic...	0.03	0.04	0.04	0.04
Sulphur, max. per cent..................	0.04	0.04	0.04	0.04
Nickel, min. per cent....................	3.25	3.25	3.25	3.25

4. To determine whether the material conforms to the requirements specified in Section 3, an analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt. A copy of this analysis shall be given to the purchaser or his representative.

5. A check analysis may be made by the purchaser from finished material representing each melt, and this analysis shall conform to the requirements specified in Section 3.

3. PHYSICAL PROPERTIES AND TESTS

6. (*a*) The steel shall conform to the following requirements as to tensile properties:

Tensile Properties from Specimen Tests

Properties considered.	Rivets.	Plates and Shapes.	Bars and Rollers (c) Unannealed.	Bars (a) and Pins (c) Annealed.
Tensile strength lb. per sq. in...........	70,000–80,000	85,000–100,000	95,000–110,000	90,000–105,000
Yield point, min., lb. per sq. in...........	45,000	50,000	55,000	52,000
Elongation in 8 in., min. per cent.......	$\frac{1,500,000}{\text{Tens. str.}}$	$\frac{1,500,000(b)}{\text{Tens. str.}}$	$\frac{1,500,000(b)}{\text{Tens. str.}}$	20
Elongation in 2 in. min., per cent.......	....	....	16	20
Reduction of area min. per cent.......	40	25	25	35

(a) Tests of annealed specimens of bars shall be made for information only.
(b) See Section 7.
(c) Elongation shall be measured in 2 in.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

7. For plates, shapes, and unannealed bars over 1 in. in thickness, a deduction of 1 from the percentage of elongation specified in Section 6 shall be made for each increase of ⅛ in. in thickness above 1 in., to a minimum of 14 per cent.

8. All broken tension test specimens shall show either a silky or a very fine granular fracture, of uniform colour, and free from coarse crystals.

9. (*a*) The test specimen for plates, shapes and bars, shall bend cold through 180 deg. without fracture on the outside of the bent portion, as follows: For material ¾ in. or under in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material over ¾ in. in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

(*b*) A rivet rod shall bend cold through 180 deg. flat on itself without fracture on the outside of the bent portion.

(*c*) The test specimen for pins and rollers shall bend cold through 180 deg. around a 1-in. pin, without fracture on the outside of the bent portion.

(*d*) Bend tests may be made by pressure or by blows.

10. (*a*) Angles with 4-in. legs or under, and ½ in. or under in thickness, shall open flat or bend shut, cold, under the blows of a hammer without fracture.

(*b*) Angles with legs over 4 in., or over ½ in. in thickness, shall open to an angle of 150 deg., or close to an angle of 30 deg., cold, under the blows of a hammer, without fracture.

11. Punched rivet holes pitched two diameters from a planed edge shall stand drifting until the diameter is enlarged 50 per cent., without cracking the metal.

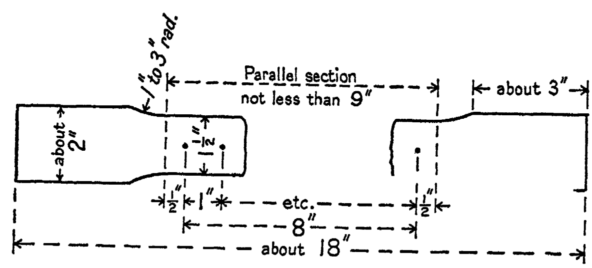


Fig. 1.

12. (*a*) Tension and bend test specimens for plates, shapes and bars shall be taken from the finished product, and shall be of the full thickness of material as rolled.

Tension test specimens may be of the form and dimensions shown in Fig. 1; or with both edges parallel; or they may be turned to a diameter of ¾ in. for a length of at least 9 in., with enlarged ends. Bend test specimens shall not be less than 2 in. in width.

(*b*) Rivet rods shall be tested as rolled.

(*c*) Tension and bend test specimens for pins and rollers shall be taken from the finished rolled or forged bar. The axis of the specimen shall be 1 in. from the

surface of the bar and shall be parallel to the axis of the bar. Test specimens for pins shall be taken after annealing.

Tension test specimens shall be of the form and dimensions shown in Fig. 2.

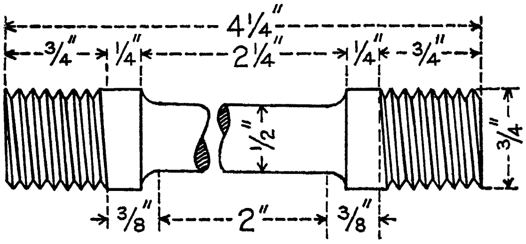


Fig. 2.

Bend test specimens shall be 2 by ½ in. in section.

13. At least one tension and one test shall be made from each melt. If material from one melt differs ⅜ in. or over in thickness, tests shall be made from both the thickest and the thinnest material rolled. No material under 5/16 in. in thickness will be used.

4. PERMISSIBLE VARIATIONS IN WEIGHT AND GAUGE

14. The cross-section or weight of each piece of steel shall not vary more than 2.5 per cent. from that specified; except in the case of sheared plates, which shall be covered by the following permissible variations to apply to single plates:

(*a*) When Ordered by Weight.—For plates 12½ lbs. per sq. ft. or over.

Under 100 in. in width, 2.5 per cent. above or below the specified weight.
100 in. in width and over, 5 per cent. above or below the specified weight.

(*b*) When ordered to Gauge.—The thickness of the plate shall not vary more than 0.01 in. below that ordered.

An excess over the nominal weight corresponding to the dimensions on the order shall be allowed for each plate, if not more than that shown in the following table, one cubic inch of rolled steel being assumed to weigh 0.2833 lb.:—

Thickness Ordered, in.	Nominal Weight, lb. per sq. ft.	Allowable Excess (expressed as percentage of Nominal Weight) For Width of Plate as follows:			
		Under 75 in.	75 in. to 100 in.	100 in. to 115 in.	115 in. and over.
5/16	12.75	8	12	16	....
3/8	15.30	7	10	13	17
7/16	17.85	6	8	10	13
1/2	20.40	5	7	9	12
9/16	22.95	4.5	6.5	8.5	11
5/8	25.50	4	6	8	10
Over 5/8................	....	3.5	5	6.5	9

5. FINISH

15. The finished material shall be free from injurious seams, slivers, flaws, and other defects, and shall have a workmanlike finish.

6. MARKING

16. The name of the manufacturer and the melt number shall be legibly stamped or rolled on all finished material, except that each pin and roller shall be stamped on the end. Rivet and lattice steel, and other small pieces shall be shipped in securely fastened bundles, with the above marks legibly stamped on an attached metal tag.

7. INSPECTION

17. The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

8. FULL-SIZE TESTS

18. (*a*) Full-size tests of annealed eye bars shall conform to the following requirements as to tensile properties:—

Tensile strength, lb. per sq. in.	85,000-100,000
Yield point, min., " "	48,000
Elongation in 18 ft., min., per cent	10
Reduction of area, " "	30

(*b*) The yield point shall be determined by the halt of the gauge of the testing machine.

Standard Specifications, New York Society of Automobile Engineers

The following standard specifications for nickel steels adopted by the Society of Automobile Engineers, New York, are taken from the transactions ~~of~~ that Society, Volume 8, part 2, 1913:—

Nickel Steels

SPECIFICATION NO. 23-15: .15 CARBON, 3½ PER CENT. NICKEL STEEL

This quality of steel is embraced in these specifications to furnish a nickel steel that is suitable for carbonizing purposes. Steel of this character, properly carbonized and heat-treated, will produce a part with an exceedingly tough and strong core, coupled with the desired high carbon exterior.

The steel is also available for structural purposes, but is not one to be selected for such purpose when ordering materials. Much better results will be obtained with one of the other nickel steels of higher carbon.

It is intended for case-hardened gears, for both the level driving and transmisson systems, and for such other case-hardened parts as demand a very tough, strong steel with a hardened exterior.

The case-hardening sequence may be varied considerably, as with steel 10-20, those parts of relatively small importance requiring a simpler form of treatment. As a rule, however, those parts which require the use of nickel-steel require the best type of case-hardening, viz.:—

HEAT TREATMENT G

After forging or machining:—

1. Carbonize at a temperature between 1600°F. and 1750°F. (1650°-1700°F. desired).
2. Cool slowly in the carbonizing material.
3. Reheat to 1500°-1550° F.
4. Quench.
5. Reheat to 1300°-1400° F.
6. Quench.
7. Reheat to a temperature from 250°-500° F. (in accordance with the necessities of the case) and cool slowly.

The second quench (operation 6) must be conducted at the lowest possible temperature at which the material will harden. It will be found that sometimes this is lower than 1300° F.

In connection with certain uses it will be found possible to omit the final drawing (operation 7) entirely, but for parts of the highest importance this operation should be followed as a safeguard. Parts of intricate shape, with sudden changes of thickness, sharp corners and the like, particularly sliding gears, should always be drawn, in order to relieve the internal strains.

PHYSICAL CHARACTERISTICS

Much is to be learned from the character of the fracture. The centre should be fibrous in appearance and the exterior, high carbon metal closely crystalline, or even silky.

When used for structural purposes, the physical characteristics will range about as follows:—

——	Annealed.	Heat Treatment, H. or K
Yield point, lbs. per sq. inch	35,000 to 45,000	40,000 to 80,000
Reduction of area	65–45 p.c.	65–40 p.c.
Elongation in 2"	35–25 p.c.	35–15 p.c.

SPECIFICATION NO. 23-20: .20 CARBON, 3½ PER CENT. NICKEL STEEL

This quality may be used interchangeably with steel 23-15. Although intended primarily for case-hardening, it may be properly used for structural parts, with suitable heat treatment, and will give elastic limits somewhat higher than material provided by the preceding specification.

For case-hardening, Heat Treatment G should be followed, and for structural purposes the treatment should be in accordance with Heat Treatment H or K; the quenching temperatures, as with other steels, being modified to meet individual cases.

PHYSICAL CHARACTERISTICS

——	Annealed.	Heat Treatment, H. or K.
Yield point, lbs. per sq. inch	40,000 to 50,000	50,000 to 125,000
Reduction of area	65–40 p.c.	65–40 p.c.
Elongation in 2″	30–20 p.c	25–10 p.c.

SPECIFICATION NO. 23-25: .25 CARBON, 3½ PER CENT. NICKEL STEEL

This is a quality of steel that may be case-hardened successfully. Suitable treatment (G) gives a product that is satisfactory for gears, whether of the transmission or rear axle bevel type. The treatment after carbonizing must be slightly modified to meet the increase in carbon content.

This is also a useful quality of steel for many structural parts, its response to heat treatment (either H or K) being most satisfactory.

PHYSICAL CHARACTERISTICS

The physical characteristics of this steel may be considered as practically those obtained with Steel 23-20, slight modifications in the treatment much more than offsetting the slight difference in the carbon content.

——	Annealed.	Heat Treatment, H. or K.
Yield point or elastic limit, lbs. per sq. inch	40,000 to 50,000	60 to 130,000
Reduction of area	60–40 p.c.	60–30 p.c.
Elongation in 2″	30–20 p.c.	25–10 p.c.

SPECIFICATION NO. 23-30: .30 CARBON, 3½ PER CENT. NICKEL STEEL

This quality of steel is primarily for heat treated structural parts where strength and toughness are sought; such parts as axles, front-wheel spindles, crankshafts, driving-shafts and transmission shafts. Wide variations of yield points or elastic limit are possible by the use of different quenching mediums—oil, water, or brine—and variations in drawing temperatures, from 500°F. up to 1200°F.

The form of treatment is—

HEAT TREATMENT H

After forging or machining—

1. Heat to 1500°-1550° F.
2. Quench.
3. Reheat to 600°-1200° F. and cool slowly.

A higher refinement of this treatment is:—

1. Heat to 1500°-1550° F.
2. Quench.
3. Reheat to 1300°-1400° F.
4. Quench.
5. Reheat to 600°-1200° F. and cool slowly.

This material may be case-hardened, but is rather high in carbon for the practice of the average case-hardening department. The lower ranges of carbon—in the neighbourhood of .25—are satisfactory, but the upper ranges—in the neighbourhood of .35—approach the danger point, and steel of the latter carbon content must be correspondingly carefully handled.

PHYSICAL CHARACTERISTICS

—	Annealed.	Heat Treatment, H. or K.
Yield point or elastic limit, lbs. per sq. inch......	45,000 to 55,000	65,000 to 150,000
Reduction of area................................	55–35 p.c.	55–25 p.c.
Elongation in 2"................................	25–15 p.c.	25–10 p.c.

SPECIFICATION NO. 23-35: .35 CARBON, 3½ PER CENT. NICKEL STEEL

This quality of steel is subject to precisely the same remarks as Steel 23-30. It will respond a little more sharply to heat treatment and can be forced to higher elastic limits. The difference will be small except in extreme cases. It should not be used for case-hardening.

PHYSICAL CHARACTERISTICS

—	Annealed.	Heat Treatment H. or K.
Yield point or elastic limit, lbs. per sq. inch.......	45,000 to 55,000	65,000 to 160,000
Reduction of area................................	55–35 p.c.	55–25 p.c.
Elongation in 2"	25–15 p.c.	25–10 p.c.

SPECIFICATIONS NOS. 23-40, 23-45 AND 23-50

These are for .40 Carbon, 3½ per cent. Nickel Steel; .45 Carbon, 3½ per cent. Nickel Steel; .50 Carbon, 3½ per cent. Nickel Steel.

The above nickel steels are qualities not in wide use, but are available for certain purposes.

The carbon contents being higher than generally used, greater hardness is obtainable by quenching; and as increased brittleness accompanies the greater hardness, the treatments given must be modified to meet such conditions. For example, the final quench may be at a considerably lower temperature, and the final drawing temperature, or partial annealing, must be carefully chosen, in order to produce the desired toughness and other physical characteristics.

The strength of these steels, as with steels 23-25, 23-30 and 23-35, depends upon the treatment and may be controlled closely over a wide range. The degree of brittleness must be carefully watched and controlled. Proper treatment will yield very strong and tough steel; not as tough as steels 23-25, 23-30 and 23-35, but nevertheless tough enough to fill a number of needs.

PHYSICAL CHARACTERISTICS

——	Annealed.	Heat Treatment, H. or K.
Yield point or elastic limit, lbs. per sq. inch.......	55,000 to 70,000	70,000 to 200,000
Reduction of area	50–30 p.c.	55–15 p.c.
Elongation in 2"	25–15 p.c.	20–5 p.c.

Nickel-Chromium Steels

These classes of alloy steel are important. There are three types in common use, the differences between them consisting in the amount of alloying elements present. The types may be classified as low nickel—medium nickel—and high nickel-chromium steels, viz., classes 31-, 32- and 33-, as given in the specifications.

In general it may be said that the heat treatments and the properties induced thereby are much the same as in the case of plain nickel steels, except that the effects of the heat treatments are somewhat augmented by the presence of the chromium, and further that these effects increase in these three types with increasing amounts of nickel and chromium.

Low Nickel-Chromium Steels

SPECIFICATIONS NOS. 31-15 TO 31-50

Substantially the same remarks apply to these various types as apply to nickel steels. In other words, the carbon content may be varied from the lowest to the highest depending upon the physical qualities sought. The physical characteristics will vary with the carbon, and the heat treatment must be chosen accordingly.

Steels 31-15 and 31-20 (.15 and .20 carbon) are intended primarily for case-hardening (Heat Treatment G). These steels ought not to be used in the natural

condition, but if desired may be used for structural purposes, in which case Heat Treatments H and K are recommended.

Steels 31-25, 31-30, 31-35, 31-40 (.25 to .40 carbon) are intended primarily for structural purposes in a heat treated condition (Heat Treatments H and K). Steel 31-25 may be used for case-hardening, as also may steel 31-30 if necessary.

Steels 31-45, 31-50 (.45 and .50 carbon) may be used for gears and other structural parts where a high degree of strength and hardness are demanded and where toughness is not of first importance. Heat Treatment K is recommended for such parts the final drawing (Operation 5) being carried out at 250°-550° F., or at such temperature as will give the desired physical characteristics.

PHYSICAL CHARACTERISTICS

——	Annealed.	Heat treatment, H. or K.
Steels 31-15, 31-20:		
Yield point or elastic limit, lbs. per sq. in.	30,000 to 40,000	40,000 to 100,000
Reduction of area	55-40 p.c.	65-40 p.c.
Elongation in 2″	35-25 p.c.	25-15 p.c.
Steels 31-25, 31-30:		
Yield point or elastic limit, lbs. per sq. in.	40,000 to 55 000	50,000 to 125,000
Reduction of area	50-35 p.c.	55-25 p.c.
Elongation in 2″	30-20 p.c.	25-10 p.c.
Steels 31-35, 31-40:		
Yield point or elastic limit, lbs. per sq. in.	45,000 to 60,000	55,000 to 150,000
Reduction of area	50-30 p.c.	50-25 p.c.
Elongation in 2″	25-15 p.c.	20-5 p.c.
Steels 31-45, 31-50:		
Yield point or elastic limit, lbs. per sq. in.	55,000 to 70,000	60,000 to 175,000
Reduction of area	45-30 p.c.	45-20 p.c.
Elongation in 2″	25-15 p.c.	15-5 p.c.

Medium Nickel-Chromium Steels

SPECIFICATIONS NOS. 32-15 TO 32-50

It will be noted that this type of nickel-chromium steel is of the same composition as the preceding type, except that it contains more nickel and more chromium. The physical characteristics are omitted, for the reason that results will be obtained that are intermediate between the low nickel chromium alloys and the high nickel chromium alloys.

High Nickel-Chromium Steels

These steels differ from the two preceding types (31- and 32-) in the fact that they contain still more nickel and chromium.

Attention is called to the fact that there will be some difference noted between the high nickel-chromium and the medium nickel-chromium heat treatments. It will be found that the possible ranges of treatment will differ slightly; also that the resulting physical characteristics will vary correspondingly.

Annealing before machining will be found necessary for all carbons. The higher percentages of alloy elements make machining in a natural condition difficult.

SPECIFICATION NO. 33-15; .15 CARBON HIGH NICKEL-CHROMIUM STEEL

This quality of steel is intended primarily for case-hardening (Heat Treatment L). It may also be used for structural purposes, but is not first choice for same.

HEAT TREATMENT L

After forging or machining—

1. Carbonize at a temperature between 1600° F. and 1750° F. (1650°-1700° F. desired).
2. Cool slowly in the carbonizing mixture.
3. Reheat to 1400°-1500° F.
4. Quench.
5. Reheat to 1300°-1400° F.
6. Quench.
7. Reheat to 250°-500° F. and cool slowly.

SPECIFICATION NO. 33-20: .20 CARBON, HIGH NICKEL-CHROMIUM STEEL

This quality of steel is also intended primarily for case-hardened parts, and when so used, demands the most careful treatment. (Heat Treatment L.)

This quality may also be used for structural purposes, but as with other alloys, there is little gain over carbon steel unless it be used in a properly heat-treated condition. The heat treatment is substantially the same sequence of operations as apply to other nickel-chromium steels dealt with herein, with such modifications as may be determined by practical experiment.

PHYSICAL CHARACTERISTICS

—	Annealed.	Heat Treatment, M. or P.
Yield point or elastic limit, lbs. per sq. in...	40,000 to 50,000	50,000 to 125,000
Reduction of area..........................	60–45 p.c.	65–30 p.c.
Elongation in 2"...........................	25–20 p.c.	20–5 p c.

SPECIFICATION NO. 33-25: .25 CARBON, HIGH NICKEL-CHROMIUM STEEL

This quality of nickel-chromium steel is intermediate between that preferred for case-hardening (Steel 33-20) and the next higher quality (Steel 33-30) for heat treated structural parts.

With the case-hardening treatment (Heat Treatment L) there may be slight modifications necessary.

When properly heat treated, this steel will answer for many structural parts. Heat Treatments M and P are recommended.

HEAT TREATMENT M

After forging or machining—

1. Reheat to 1375°-1425° F.
2. Quench.
3. Reheat to a temperature between 500° F. and 1250° F. and cool slowly.

A higher refinement of this same treatment is:—

HEAT TREATMENT P

After forging or machining—

1. Heat to 1450°-1500° F.
2. Quench.
3. Reheat to 1375°-1425° F.
4. Quench.
5. Reheat to a temperature between 500° F. and 1250° F. and cool slowly.

PHYSICAL CHARACTERISTICS

——	Annealed	Heat Treatment, M. or P.
Yield point or elastic limit, lbs. per sq. in. ..	40,000 to 50,000	60,000 to 140,000
Reduction of area..........................	60–45 p.c.	65–30 p.c.
Elongation in 2″............................	25–20 p.c.	20–5 p.c.

SPECIFICATION NO. 33-30: .30 CARBON, HIGH NICKEL-CHROMIUM STEEL

This grade of nickel-chromium steel is intended primarily for structural parts of the most important character; and should always be heat treated.

This quality is suitable for crank-shafts, axles, spindles, drive-shafts, transmission shafts and, in fact, the most important structural parts of cars.

The heat treatment recommended is the same as in the case of steel 33-25.

This steel is not intended for case-hardening. If case-hardening be attempted, the highest degree of care must be exercised.

PHYSICAL CHARACTERISTICS

——	Annealed.	Heat Treatment, L. or M.
Yield point or elastic limit, lbs. per sq in...	45,000 to 55,000	60,000 to 175,000
Reduction of area..........................	55–40 p.c.	60–30 p.c.
Elongation in 2″............................	25–15 p.c.	20–5 p.c.

SPECIFICATION NO. 33-35: .35 CARBON, NICKEL-CHROMIUM STEEL

Substantially the same remarks apply to this steel as apply to steel 33-30. The carbon content is but five points higher, and the physical characteristics, either annealed or otherwise heat-treated, will not differ materially from those given for steel 33-30, and are repeated below. This quality should not be used for case-hardening.

PHYSICAL CHARACTERISTICS

——	Annealed.	Heat Treatment, M. or P.
Yield point or elastic limit, lbs. per sq. in...	45,000 to 55,000	60,000 to 175,000
Reduction of area..........................	55–40 p.c.	60–30 p.c.
Elongation in 2″...........................	25–15 p.c.	20–5 p.c.

SPECIFICATION NO. 33-40: .40 CARBON, HIGH NICKEL-CHROMIUM STEEL

This quality of steel is suitable for structural parts where unusual strength is demanded. Higher elastic limit is possible under a given treatment than with material like steels 33-30 or 33-35. The toughness will not be quite as great, but this does not bar the material from uses where toughness is not the controlling factor and where strength is.

Heat Treatment P is recommended.

This steel should be thoroughly annealed for machining.

This quality of steel should not be case-hardened.

PHYSICAL CHARACTERISTICS

——	Annealed.	Heat Treatment P.
Yield point or elastic limit, lbs. per sq. in...	50,000 to 60,000	65,000 to 200,000
Reduction of area..........................	50–40 p.c.	50–20 p.c.
Elongation in 2″...........................	25–15 p.c.	15–2 p.c.

SPECIFICATION NO. 33-45: .45 CARBON, HIGH NICKEL-CHROMIUM STEEL

The use of this steel is largely for gears, where extreme strength and hardness are necessary. The carbon is sufficiently high to cause the material, in the presence of chromium and nickel, to become hard enough to make a good gear when quenched, without case-hardening (carbonizing).

This steel is difficult to forge. During the forging operation it should be kept at a thoroughly plastic heat and not hammered or worked after dropping to ordinary forging temperatures; otherwise cracking is liable to follow. The steel also becomes so very hard as to forge with great difficulty. On the other hand, too

high a temperature is not advisable, as the steel becomes red-hot and breaks. In brief, the forging temperature limits are narrow and this steel must be reheated more frequently than any other steels dealt with in this report.

To heat treat for gears, either Heat Treatment Q or R is used, the latter giving the best results:

HEAT TREATMENT Q

After forging—

1. Reheat to 1475°-1525°F. (hold at this temperature one-half hour to insure thorough heating).
2. Cool slowly.
3. Reheat to 1450°-1500° F.
4. Quench.
5. Reheat to 250°-550° F. and cool slowly.

This steel should be thoroughly annealed for machining—Operations 1 and 2.

The final drawing operation must be conducted at a heat which will produce the proper degree of hardness. The desired Brinell hardness for a gear is between 430 and 470 the corresponding Shore hardness being from 75 to 85.

This quality of steel should not be case-hardened.

PHYSICAL CHARACTERISTICS

—	Annealed.	Heat Treatment Q.
Yield point or elastic limit, lbs. per sq. in...	50.000 to 60,000	150,000 to 250,000
Reduction of area..........................	50–40 p.c.	25–15 p.c.
Elongation in 2"............................	25–15 p.c.	15–2 p.c.

HEAT TREATMENT R

After forging—

1. Heat to 1500°-1550° F.
2. Quench in oil.
3. Reheat to 1200°-1300° F. (Hold at this temperature three hours).
4. Cool slowly.
5. Machine.
6. Reheat to 1350°-1450° F.
7. Quench in oil.
8. Reheat to 250°-500° F. and cool slowly.

Nickel-Chromium-Vanadium Steels

SPECIFICATIONS 41 AND 42

The heat treatments and remarks as to application for this class of steels are essentially the same as for classes 31- and 32-. The physical characteristics obtained are very similar.

Amended Classification of Nickel and Nickel-Chromium Steels

The Society of Automobile Engineers (Volume 9, Part 2, 1914) recommends that the terms "low," "medium," and "high" be discontinued in the classification of nickel-chromium steels.

They recommend certain other alterations and additions which are included in the following specifications:—

Nickel Steels

SPECIFICATION NO. 2315

	Per cent.	
Carbon	.10 to .20	(.15 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	3.25 to 3.75	(3.50 desired)

SPECIFICATION NO 2320

	Per cent.	
Carbon	.15 to .25	(.20 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	3.25 to 3.75	(3.50 desired)

SPECIFICATION NO. 2330

	Per cent.	
Carbon	.25 to .35	(.30 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	3.25 to 3.75	(3.50 desired)

SPECIFICATION NO. 2335

	Per cent.	
Carbon	.30 to .40	(.35 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	3.25 to 3.75	(3.50 desired)

SPECIFICATION NO. 2340

	Per cent.	
Carbon	.35 to .45	(.40 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	3.25 to 3.75	(3.50 desired)

Nickel-Chromium Steels

SPECIFICATION NO. 3120

	Per cent.	
Carbon	.15 to .25	(.20 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	1.00 to 1.50	(1.25 desired)
Chromium [1]	.45 to .75	(.60 desired)

SPECIFICATION NO. 3125

	Per cent.	
Carbon	.20 to .30	(.25 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	1.00 to 1.50	(1.25 desired)
Chromium [1]	.45 to .75	(.60 desired)

SPECIFICATION NO. 3130

	Per cent.	
Carbon	.25 to .35	(.30 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	1.00 to 1.50	(1.25 desired)
Chromium [1]	.45 to .75	(.60 desired)

SPECIFICATION NO. 3135

	Per cent.	
Carbon	.30 to .40	(.35 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	1.00 to 1.50	(1.25 desired)
Chromium [1]	.45 to .75	(.60 desired)

SPECIFICATION NO. 3140

	Per cent.	
Carbon	.35 to .45	(.40 desired)
Manganese	.50 to .80	(.65 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.045	
Nickel	1.00 to 1.50	(1.25 desired)
Chromium [1]	.45 to .75	(.60 desired)

SPECIFICATION NO. 3220

	Per cent.	
Carbon	.15 to .25	(.20 desired)
Manganese	.30 to .60	(.45 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	1.50 to 2.00	(1.75 desired)
Chromium	.90 to 1.25	(1.10 desired)

SPECIFICATION NO. 3230

	Per cent.	
Carbon	.25 to .35	(.30 desired)
Manganese	.30 to .60	(.45 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	1.50 to 2.00	(1.75 desired)
Chromium	.90 to 1.25	(1.10 desired)

[1] Another grade of this type of steel is available with chromium content of .15 per cent. to .45 per cent. The physical properties of this grade are somewhat lower than those of the grade with the chromium content indicated in specifications Nos. 3120, 3125, 3130, 3135 and 3140.

SPECIFICATION NO. 3240

	Per cent.	
Carbon	.35 to .45	(.40 desired)
Manganese	.30 to .60	(.45 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	1.50 to 2.00	(1.75 desired)
Chromium	.90 to 1.25	(1.10 desired)

SPECIFICATION NO. 3250

	Per cent.	
Carbon	.45 to .55	(.50 desired)
Manganese	.30 to .60	(.45 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	1.50 to 2.00	(1.75 desired)
Chromium	.90 to 1.25	(1 10 desired)

SPECIFICATION NO. X3315

	Per cent.	
Carbon	.10 to .20	(15 desired)
Manganese	.45 to .75	(.60 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	2.75 to 3.25	(3.00 desired)
Chromium	.60 to .95	(.80 desired)

SPECIFICATION NO. X3335

	Per cent	
Carbon	.30 to .40	(.35 desired)
Manganese	.45 to .75	(.60 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	2.75 to 3.25	(3.00 desired)
Chromium	.60 to .95	(.80 desired)

SPECIFICATION NO. X3350

	Per cent.	
Carbon	.45 to .55	(.50 desired)
Manganese	.45 to .75	(.60 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	2.75 to 3.25	(3.00 desired)
Chromium	.60 to .95	(.80 desired)

SPECIFICATION NO. 3320

	Per cent.	
Carbon	.15 to .25	(.20 desired)
Manganese	.30 to .60	(.45 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	3.25 to 3.75	(3.50 desired)
Chromium	1.25 to 1.75	(1.50 desired)

SPECIFICATION NO. 3340

	Per cent.	
Carbon	.35 to .45	(.40 desired)
Manganese	.30 to .60	(.45 desired)
Phosphorus, not to exceed	.04	
Sulphur, not to exceed	.04	
Nickel	3.25 to 3.75	(3.50 desired)
Chromium	1.25 to 1.75	(1.50 desired)

PHYSICAL PROPERTIES OF NICKEL ALLOYS

Nickel and Iron

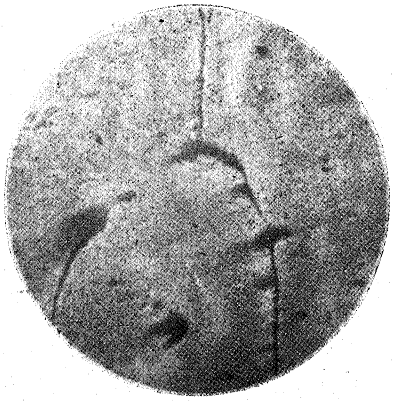
Nickel and iron alloy in all proportions, the liquidus and solidus forming a regular curve slightly concave between the melting point of iron and that of nickel. At the iron end of the series, a solid solution of beta nickel in gamma iron is formed upon solidification. At the nickel end, solid solutions of gamma iron in beta nickel are obtained. The magnetic properties are extremely interesting. Commencing at the nickel end, the magnetic change-point is raised until it reaches a maximum at 68 per cent. of nickel, which percentage roughly corresponds to the compound Ni_2Fe. The minimum freezing temperature also synchronizes with the same percentage. As the percentage of nickel further decreases, the magnetic change is lowered and becomes distinctly more irreversible until, at about 25 to 30 per cent. of nickel the metal is non-magnetic at normal temperatures. According to Dumas,[1] alloys of nickel containing just above 30 per cent. are non-magnetic at extremely low temperatures. As the nickel contents are progressively lowered, the magnetic change-point gradually rises with the temperature from zero, to the normal temperature for pure iron. It is, therefore, obvious that the magnetic properties of both iron and nickel are very seriously modified by the addition of the one element to the other. The addition of nickel to iron depresses the Ar_3 and Ar_2 points simultaneously until, with 4 to 5 per cent. of nickel, they merge into one critical point. The magnetic phenomena of the nickel-iron alloys up to 25 per cent. are irreversible to an abnormal degree. To sum up, nickel alloys may be divided into two distinct classes, those poor in nickel being non-reversible, a wide range of temperature separating the magnetic change-point on heating and cooling, and those rich in nickel which are practically reversible, i.e., the magnetic change takes place on heating and cooling at practically the same temperature. Other researches of interest in this connection are those by Guillaume[2] and Osmond.[3]

Nickel and Carbon

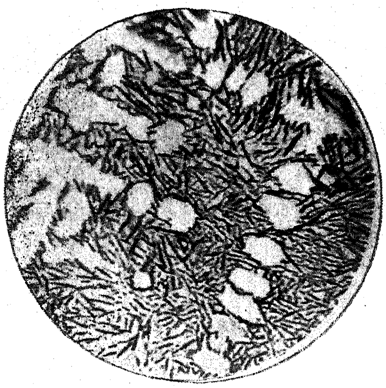
Nickel dissolves carbon and produces a nickel-carbon system. This series has been investigated by Friedrich and Leroux[4] by means of cooling curves and the microscope. Carbon lowers the melting point of nickel gradually until, when a percentage of carbon is reached between 2.0 and 2.5 per cent., a eutectic line is found at a temperature of just over 1300° C. On the breaking down of the eutectic, it was found that the nickel held the carbon in solid solution to the extent of about 1 per cent. The microscopic investigation confirmed the thermal data, and it was noted that a 2.6 per cent. carbon alloy clearly showed the presence of the primary crystals of what was possibly a carbide of nickel. It was considered that there was no evidence of the existence of the critical points similar to those found in the iron-carbon series. It is to be presumed that, with decreasing temperature, the maximum carbon content of the solid solution was gradually lowered, the carbon being thrown out as free carbon. The solid solution of carbon in nickel is stated to be

[1] Compt. Rend., May 14th, 1900.
[2] Ibid., Vol. CXXIV, p. 1515.
[3] Ibid., Vol. CXXVIII, p. 304.
[4] Metallurgie, 7, pp. 10-13, January 8th, 1910

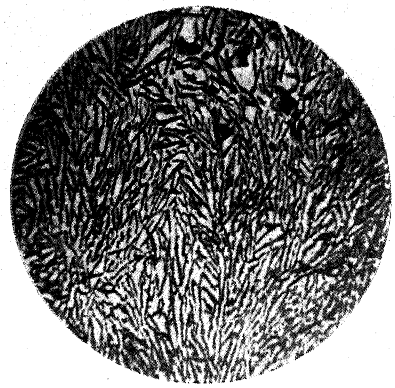
brittle. The photo-micrographs Nos. 1, 2 and 3 represent the structure obtained in alloys containing 0.8 and 2.6 per cent. of carbon, which presumably consists of a matrix of nickel of uncertain carbon content containing the small graphitic flakes in the form indicated in the micrographs. It has not yet been determined whether the carbon is in solution as carbide of nickel or as the element carbon. If an analogy with the iron-carbon system can be drawn, it might be inferred that the



No. 1. Nickel containing 0.8 per cent. C.



No. 2. Nickel containing 1.8 per cent. C.



No. 3. Nickel containing 2.6 per cent. C.

nickel, when in solution, exists as nickel-carbide but that, immediately it is thrown out of solid solution, it is decomposed.

Ruff and Martin[1] have further investigated the solubility of carbon in nickel between the temperatures of 1,500° C. and 2,500° C. Their experiments indicate that, at high temperatures, the molten nickel absorbs carbon to such an extent that at 2,100° C. the percentage is 6.42. This would correspond roughly with the compound Ni_3C. At higher temperatures, the solubility according to these observers, would appear to be slightly less.

Our knowledge concerning the carbon-nickel system is very far from complete, and much more work will be required before it can be discussed with any degree of certainty.

[1] Metallurgie, Vol. IX, pp. 143-148.

The Influence of Nickel on Low-Carbon Steels

Although the use of nickel steel may be considered as the slow growth of the last thirty years, it is of extreme commercial importance. Following the work of James Riley and others already referred to, Rudeloff,[1] in 1896 and 1897, made similar investigations, and from time to time published subsequent researches extending the original work. The research presented by Sir Robert Hadfield[2] in 1898 forms a very complete work on the subject; and also contains a summary of previous work. His series of alloys were cast in the form of 2½ inch ingots 30 inches in length and were investigated subsequently after various treatments. The analyses of the series were as follows:—

Specimen Mark	Actual Analysis C.	Si.	S.	P.	Mn.	Ni.	Intended Percentage of Ni.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
A	0.19	0.31	0.10	0.09	0.79	0.27	0.25
B	0.14	0.20	....	....	0.75	0.51	0.50
C	0.13	0.23	....	....	0.72	0.95	1.00
D	0.14	0.21	0.08	0.07	0.72	0.92	2.00
E	0.19	0.20	....	....	0.65	3.82	4.00
F	0.18	0.31	....	....	0.65	5.81	6.00
G	0.17	0.28	0.11	0.08	0.68	7.65	8.00
H	0.16	0.20	....	....	0.86	9.51	10.00
I	0.18	0.22	....	....	0.93	11.39	12.00
J	0.23	0.24	0.11	0.05	0.93	15.48	16.00
K	0.19	0.27	....	....	0.93	19.64	20.00
L	0.16	0.30	....	....	1.00	24.51	25.00
M	0.14	0.38	....	....	0.86	29.07	30.00
N	0.16	0.31	0.08	0.06	1.08	49.65	50.00

It will be seen that, while the nickel content increases from 0.27 to 49.65 per cent., the carbon is consistently between 0.13 and 0.23 per cent. Hadfield records that manganese and aluminium were added to ensure sound ingots and good working characteristics. The figures obtained as the result of the mechanical tests performed upon the alloys are given in the following table:—

Specimen Mark	A Analysis C.	Mn.	Ni.	A Unannealed Test-bars. Load in Tons per square inch Elastic Limit	Breaking load	Elongation	Reduction of Area	A Annealed Test-bars. Load in Tons per sq. inch Elastic Limit	Breaking Load	Elongation	Reduction of Area
				Tons	Tons	Per cent	Per cent.	Tons	Tons	Per cent	Per cent.
A	0.19	0.79	0.27	19	31	35	56	20	28	37	52
B	0.14	0.75	0.51	20	30	36	62	21	27	41	63
C	0.13	0.72	0.95	25	33	31	53	20	27	41	63
D	0.14	0.72	1.92	26	34	33	55	22	31	36	53
E	0.19	0.65	3.82	28	37	30	54	25	33	35	55
F	0.18	0.65	5.81	28	41	27	40	28	37	33	51
G	0.17	0.68	7.65	31	49	26	42	30	45	26	41
H	0.16	0.86	9.51	42	85	9	18	32	56	2	2
I	0.18	0.93	11.39	65	94	12	24	45	89	12	26
J	0.23	0.93	15.48	55	94	3	2	......	68	1	1
K	0.19	0.93	19.64	47	91	7	6	45	87	5	4
L	0.16	1.00	24.51	32	77	13	14	25	78	14	8
M	0.14	0.86	29.07	25	38	33	44	16	37	48	51
N	0.16	1.08	49.65	No	test		made	15	36	49	53

[1] Verhandlungen des Ver zur. Beforderung des Gewerbfleisses, 1898, p. 65.
[2] Proceedings of the Institution of Civil Engineers, 1898, Vol. 138, p. 1.

Specimen Mark	B				C		D		E	
	Load in Tons per square inch				Cast Bending Strips		Forged Bending Strips		Corrosion Tests on Forged Materials	
	Forged Compression Tests (Unannealed Material)		Cast Compression Tests (Annealed Material)							
	Elastic Limit	Shortening per cent. by 100 tons	Elastic Limit	Shortening per cent. by 100 tons	Unannealed. Bent to	Annealed. Bent to	Unannealed. Bent to	Annealed. Bent to	Loss in Grams.	Loss
	Tons	Per cent.	Tons	Per cent						Per cent
A	22	50	....	....	18°	154°	Double	Double	....	......
B	22	50	....	....	29°	80°	Double	Double	....	......
C	20	49	....	....	91°	85°	Double	Double	2.003	3.23
D	27	47	....	....	150°	Double	Double	Double	....	......
E	28	41	....	....	24°	100°	90	Double	1.611	2.95
F	40	37	....	....	11°	71°	Double	Double	....	......
G	40	33	....	....	Nil	41°	26°	89°	1.581	2.77
H	70	3	....	....	2°	8°	28°	5°	....	......
I	100	1	U66 A57	5 3	3°	9°	22°	3°	1.390	2.60
J	80	1	....	....	2°	11°	No test	made	....	......
K	80	3	....	....	2°	3°	18°	17°	....	......
L	50	16	....	....	12°	10°	No test	made	0.118	1.33
M	20	41	....	....	163°	64°	Double	Double	0.759	1.47
N	No	test	made		53°	19°	No test	made	....	......

It was found that these steels all hammered without difficulty. In each of the series, whether annealed or in the "as forged" condition, the specimens were cogged to $1\frac{1}{4}$ inches and then machined for testing.

The results obtained are of extreme scientific and technical interest. As the nickel percentage is increased, the physical properties of the material are fundamentally modified. Whereas with 0.27 per cent. of nickel, a breaking load of 31 tons is recorded with 35.0 per cent. elongation; when 11.39 per cent. of nickel is attained, this maximum stress is raised to 94 tons per sq. inch and the material becomes strangely lacking in ductility. As the nickel content is further increased, it will be seen that the ductility is restored to such an extent that, with 29.0 per cent. of nickel, the breaking load is brought down to 38 tons, with the elongation again exceeding 30.0 per cent. The analyses of these three particular specimens to which reference is here made are comparable, and this series brings out in a very clear manner, the influence which nickel has upon low-carbon steel. It is to be noted that, in both the annealed and unannealed conditions, it is not until upwards of 3.0 to 4.0 per cent. of nickel is attained, that any great change in the physical properties occurs, and it may be pointed out that the annealing of the high tensile alloys I, J and K does not restore the ductility. This emphasizes the fact, as will be shown later, that the influence of the nickel consists in modifying the physical properties of the iron itself and not, in low-carbon material, by an indirect influence upon the carbon. Sir Robert Hadfield gives much information relating to the magnetic properties, thermal phenomena, etc., associated with these alloys. Suffice it to say that the critical points are considerably affected, the carbon change being depressed to 130° C. in sample J, whilst in L the recalescence does not take place prior to ordinary temperatures being reached.

An interesting research on iron-nickel alloys has been published by Arnold and Read[1] and is worthy of careful study. Their results are given in the following table:

[1] Institution of Mechanical Engineers, 1914.

Tests on Low Carbon Iron-Nickel Alloys by Arnold and Read

Steel from Ingot Nos.	Rolled Sections	Chemical Analysis								Yield Point	Mechanical Tests				Condition of Steel	Specific Gravity	Hardness on Moh's Scale
		Nickel	Combined Carbon	Graphite	Manganese	Silicon	Sulphur	Phosphorus	Aluminum		Maximum Stress	Elongation on 2 inches	Reduction of Area	Cold Bends over $\frac{5}{8}$-in. Radius			
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Tons per sq. in.	Tons per sq. in.		Per cent.				
546 AR	2 in. × $\frac{3}{16}$ in. strip	6.42	0.11	......	0.07	0.03	0.03	0.02	0.02	30.46	39.76	30.0	43.6	....	As received from rolling mill	......	....
545 AR	"	12.88	0.14	......	0.10	0.04	0.03	0.02	0.02	60.39	80.56	13.5	30.8	....	"	......	....
512 AR	"	33.45	0.10	......	0.35	0.09	0.03	0.02	0.02	28.86	38.92	33.0	46.1	180° Unbroken	"	8.065	4.5 (between Fluorspar and Apatite)
511 AR	"	33.66	{0.05 T.C.}	{1.25 1.30}	0.21	0.03	0.04	0.02	0.02	25.88	28.23	3.0	7.3	....	"	7.795	....
549 AR	$\frac{5}{8}$ in. round	7.24	0.12	......	0.12	0.06	0.03	0.02	0.02	32.5	38.2	27.5	69.2	180° Unbroken	"	7.855	4 (Fluorspar)
548 N	"	12.78	0.10	......	0.19	0.05	0.05	0.02	0.02	58.75	88.10	11.0	45.8	167° Broken. Bent very stiffly	Normalized	7.855	*5 (Apatite)
548 A	"	"	"	......	"	"	"	"	"	54.50	79.50	10.5	38.5	....	Drastically Annealed	......	....
548 H	"	"	"	......	"	"	"	"	"	62.20	91.3	10.0	44.5	....	Quenched	......	....

* This is also the mass hardness of normal iron pearlite; the Hardenite resulting from the thermal transformation of iron pearlite has a scale hardness of 7 (Quartz).

The figures are entirely in agreement with those obtained by Hadfield in 1899, and emphasize the important influence which nickel has, even in the comparative absence of carbon. Bar 511 AR is of special interest and illustrates the relative influence when the carbon in such material is increased to 1.30 per cent. It will be seen that, with this carbon content and 33.0 per cent. of nickel, the carbon is thrown out as free carbon with the inevitable result that the ductility is very seriously decreased, as will be seen when comparison is made with 512 AR. Alloy 548 is instructive; neither a drastic annealing nor sudden quenching seriously modifying the characteristics of this 12.8 per cent. nickel alloy, which is explained by the fact that the original structure is austenitic, and hence its internal architecture is not seriously modified by either of these treatments.

A valuable series of nickel steels was prepared and examined by L. Guillet ("Les Aciers Speciaux") which consisted of three sets of steels containing respectively 0.12, 0.22 and 0.82 per cent. of carbon with variable nickel contents; the results are epitomised in the seventh Alloys Research Report to the Institution of Mechanical Engineers, 1905. The figures as there presented are given in the following table:—

Nickel Steels with Varying Carbon Content

Content of Nickel	SERIES I. Average content of Carbon = 0.12 per cent.			SERIES II. Average content of Carbon = 0.22 per cent.			SERIES III. Average content of Carbon = 0.82 per cent.		
	Yield Point	Maximum Stress	Elongation	Yield Point	Maximum Stress	Elongation	Yield Point	Maximum Stress	Elongation
Per cent.	Tons	Tons	Per cent.	Tons	Tons	Per cent.	Tons	Tons	Per cent.
2	18.8	22.8	23	19.4	26.5	21	28.9	57.5	15.7
5	19.3	26.0	25	22.9	31.6	20	37.0	64.2	10.0
7	21.2	28.6	21	26.0	36.3	20	57.0	57.0	0
10	33.4	41.4	8	52.8	67.3	3.5	67.4	67.4	3.0
12	39.1	61.0	3.5	55.5	78.8	4.0	52.7	52.7	0.5
15	54.6	62.2	0.5	45.1	72.4	5.5	21.5	28.9	4.0
20	52.5	76.0	15.0	56.2	80.8	4.5	23.3	36.0	9.5
25	30.0	61.6	5.0	18.2	34.7	29	24.2	47.7	22.0
30	18.7	28.6	29.5	21.1	35.6	32	30.5	50.6	32.5

It will be seen that the increase in tenacity recorded by Hadfield is here confirmed but, at the same time, the carbon content materially influences the percentage of nickel necessary for the maximum effect. There is considerable irregularity in the figures, but it is obvious that, with increasing carbon content, less nickel is required to produce the effect under discussion.

Consideration should also be given to the very valuable research resulting from the combined efforts of Dr. Carpenter, Sir Robert Hadfield and Dr. Longmuir, which formed the subject of the alloys research above referred to. This work deals

, FORGED AND COOLED FROM 800° C. (1,472° F.)

Ni. Alloy.	Analyses.			Bending Test.	Tensile Tests.			Tensile Tests.		Torsion Tests.		Compression at 100 tons per sq. in.	Modulus of Elasticity.
	Ni.	C.	Mn.		Yield Point.	Maximum Stress.	Elastic Ratio.*	Elongation on 2 inches.	Reduction of Area.	Twisting Moment.	Angle of twist at fracture.		
	Per cent.	Per cent.	Per cent.	Bent to	Tons per sq. inch	Tons per sq. inch.		Per cent.	Per cent.	Inch-lbs.	Degrees.	Per cent.	Lbs. per sq. inch.
A	—	0.47	0.95	180° U.	21.00	38.19	0.55	25.0	51.73	4,277	—	36.98	32,100,000
B	1.20	0.48	0.75	180° U.	23.93	40.93	0.58	21.0	42.80	5,077	405	36.21	30,700,000
C	2.15	0.47	0.86	180° U.	23.67	41.52	0.57	24.5	51.83	5,609	621	37.54	30,500,000
D	4.25	0.40	0.82	180° U.	29.16	47.86	0.61	20.0	33.06	5,071	468	31.13	29,900,000
E	4.95	0.42	1.03	30° B.	33.95	60.09	0.56	2.0	3.71	6,429	177	6.64	29,500,000
F	6.42	0.52	0.92	10° B.	None detected	110.57	—	Nil	Nil	7,497	42.6	5.73	28,000,000
G	7.95	0.43	0.79	5° B.	None detected	77.38	—	Nil	Nil	7,938	20.1	3.57	27,300,000
H	12.22	0.41	0.85	10° B.	34.56	80.24	0.43	1.0	1.63	8,621	31.5	7.52	27,500,000
J	15.98	0.45	0.83	60° B.	28.53	80.24	0.35	5.5	7.33	7,329	118.5	9.31	27,400,000
K	19.91	0.41	0.96	180° U.	15.33	43.92	0.35	55.0	63.11	5,662	690	29.94	29,600,000
1	2	3	4	5	6	7	7a	8	9	10	11	12	13

In column 5, U signifies Unbroken. B. Broken

* Added after Discussion.

FORGED AND COOLED FROM 800° C. (1,472° F.)

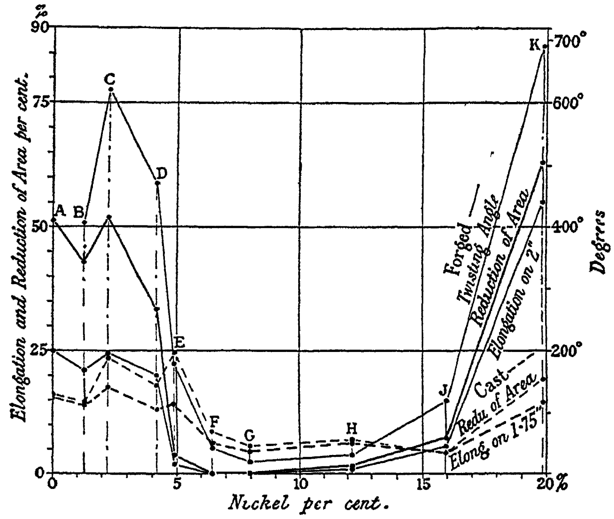
Ni Alloy.	Shock Tests. Fall of 46.7 lbs Hammer.	Shock Tests. Energy absorbed.	Shock Tests. Bending Angle.	Hardness Tests. Indentations in $\frac{1}{1000}$ inch. Load in tons 1.5	Hardness Tests. Indentations in $\frac{1}{1000}$ inch. Load in tons 2.5	Hardness Tests. Brinell Ball Test. Hardness No. (Normalized specimens)	Specific Gravities at 17–18° C (62.6-64.4° F)	Specific Volume at 17–18° C (62.6-64.4° F.)	Dilatations Coefficients × 10^6	Resistivities Microhm Cm. at 17° C (62.6° F.)	Corrosion Tests. Percentage Loss. After 32 days in water.	Corrosion Tests. Percentage Loss. After 33 days in sea-water.	Corrosion Tests. Percentage Loss. After 17 days in 50 per cent. Sulphuric acid
	Inches.	Inch Pounds.	Degrees.										
A	13.23	451	18.0	7.2	15.0	202	7.880	0.1269	—	20.3	0.15	—	0.80
B	13.05	428	17.0	6.4	14.5	207	7.890	0.1267	11.22	22.6	0.11	0.23	1.10
C	13.67	454	16.5	7.0	19.5	212	7.884	0.1268	11.12	24.8	0.10	0.26	0.72
D	13.92	460	15.5	6.0	12.3	217	7.867	0.1271	11.36	29.1	0.11	0.26	0.71
E	13.67	217	Broken O	4.2	8.7	321	7.876	0.1270	12.07	39.3	0.12	0.24	0.66
F	13.67	105	Broken O	2.5	5.5	532	7.885	0.1268	12.23	42.8	0.12	0.23	0.58
G	14.15	230	Broken O	2.5	5.7	578	7.883	0.1269	12.13	43.9	0.12	0.23	0.54
H	14.17	436	7.5	3.2	6.2	555	7.904	0.1265	13.28	50.5	0.10	0.23	0.44
J	13.33	432	11.5	5.0	10.3	293	8.026	0.1246	17.54	63.3	0.09	0.18	0.28
K	13.77	452	28.0	16	40	131	8.122	0.1231	19.65	75.4	0.09	0.14	0.28
	14	15	16	17	18	19	20	21	22	23	24	25	26

with steels containing 0.45 per cent. of carbon, and may be considered as an absolute proof of the value of nickel when added to steel. The alloys were prepared at the Hecla Works of Messrs. Hadfields, Ltd., from Swedish charcoal iron, nickel and carbon being added by means of metallic nickel and Swedish white iron. The ingots were cast 24 inches long by 2.4/5 inches by 2½ inches. The foregoing table contains the more important data:—

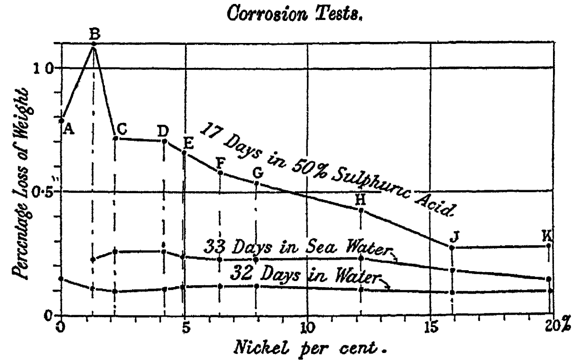
The accompanying diagrams are selected from the original work as showing

Tensile Tests.

Elongation, Reduction of Area, and Twisting Angle.



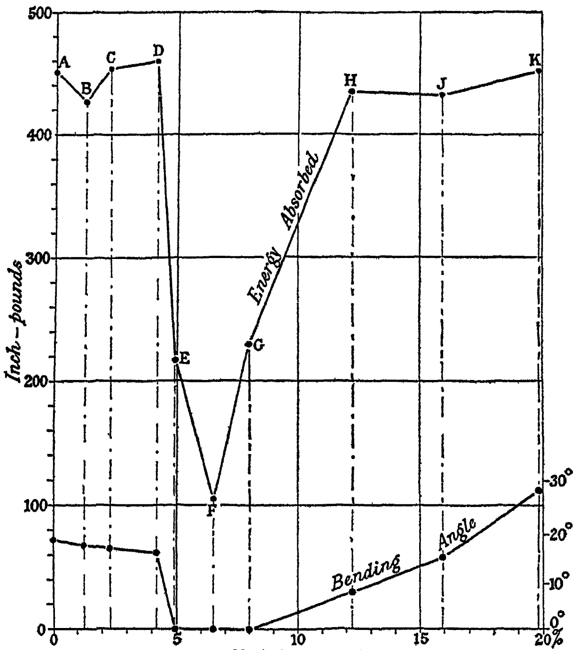
Corrosion Tests.



clearly the results obtained during the experiments. The table of figures, with the assistance of the diagrams, will convey a very good idea of the alteration in physical properties brought about by the gradual increase in the content of nickel up to 20.0 per cent.

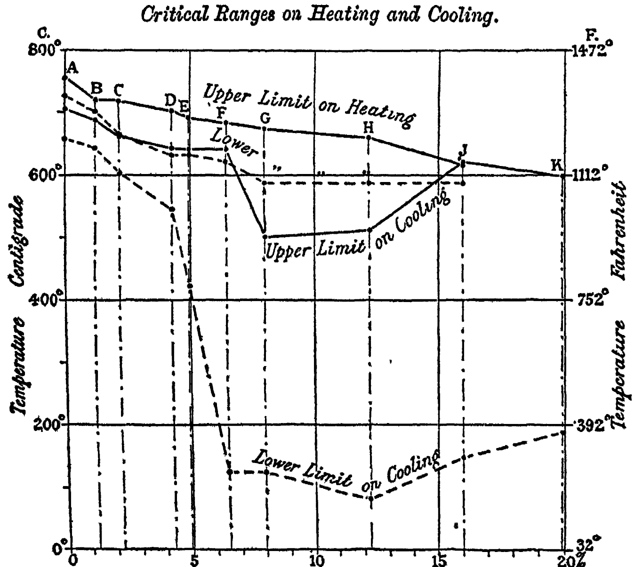
The freezing temperatures of this series of alloys were determined by the investigators, but their results do not point to any important influence of nickel in this direction, and considering the small effect which nickel has upon the

Impact Tests.



freezing point of pure iron, little difference was to be expected. The commencement of freezing averaged throughout the series a little above 1,400°C., whilst the completion (with exceptions) was in the neighbourhood of 1,250°C. The carbon change-point was observed, however, to be very materially affected, and was found to cover a range of increasing magnitude with increasing nickel content, rather than to present a definite point as in the iron-carbon series of alloys. The effect of

Critical Ranges on Heating and Cooling.



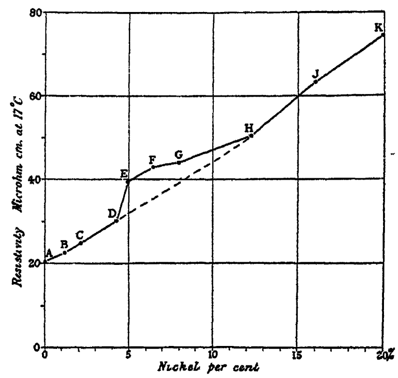
the nickel is to depress the temperature at which the separation of carbide from the solid solution takes place to such an extent that, with 20.0 per cent. of nickel, it may be considered that the breaking down of the solid solution becomes practically suppressed. This influence of nickel is naturally the predominating factor in determining the microstructure, and incidentally the mechanical properties, of the nickel alloys. The thermal phenomena are indicated in the diagram shown on the preceding page.

Effect of Nickel Upon Resistivity and Permeability

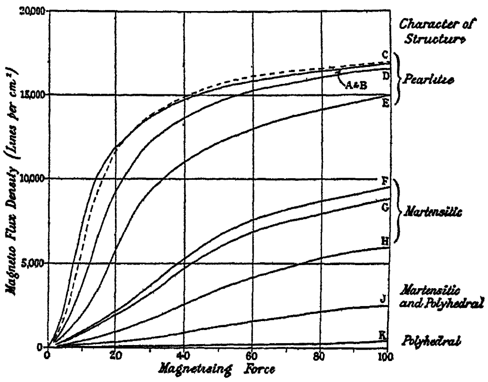
The alloys experimented upon by the Seventh Alloys Research Workers were studied in this connection, and the curve produced is of special interest when the data are compared with the various other modifications in properties brought about by the gradual increase of nickel. The sudden change in the alloy E is "coincident with a structural change in the series, and constitutes additional evidence of the sharp break in the continuity of the properties of the series."

As regards permeability, it is stated that the pearlitic steels gave the highest values, the martensitic very much lower values, while the polyhedral steel K is the lowest of all. To those interested, the following diagrams will be instructive:—

Resistivities



Permeabilities



Influence of Nickel on High Carbon Steels

The addition of nickel to high carbon steels results in the carbon being liberated in the free state. This naturally destroys the value of the steel, so that no useful purpose is served by adding nickel to the higher carbon materials. G. B. Waterhouse[1] has made experiments to determine the influence of heat-treatment upon the higher carbon steels containing 3.8 per cent. of nickel, and the results of his observations upon the thermal phenomena of this series of steels have been published. Further experiments[2] were made to determine the temperature of over-heating for such material, and consisted in heating them to temperatures of 1,000°, 1,100°, 1,200°, 1,300°, 1,400° and 1,460°C. in a specially constructed furnace. They were

[1] Journal of the Iron and Steel Institute, 1905, No. II, p. 376.
[2] Proc. of the Amer. Soc. for Testing Materials, 1906, Vol. VI.

allowed to remain at the maximum temperature for one hour, and then allowed to cool gradually inside the furnace. He found that the two highest carbon steels contained temper carbon after the heat-treatment, and he came to the conclusion that, in all high carbon steels, when temperatures of 1,000°C. and over were attained, followed by slow cooling, free carbon resulted. He states that upon again heating to high temperatures, this temper carbon went back into solution, but it is to be presumed that, on slow cooling, it would again appear in the final material as temper carbon.

With relation to the influence of nickel when added to the higher carbon alloys, it is of interest to note that L. Guillet[1] has published the results of some experiments dealing with alloys of cast iron composition. The experiments consisted of two series of alloys. In the first series, nickel was added to grey iron, while in the second, white iron was used as the basis. In the first series, the nickel content ranged from 2.73 to 12.0 per cent., whilst in the latter, as much as 48.27 per cent. was added. He considers that the results of his experiments justify conclusions on the following lines:—

Under the influence of quite small additions of nickel, the pearlite tends to disappear, or at least to take the sorbitic form, whilst the cementite decreases and assumes the acicular form. When considerable quantities of nickel are present, he suggests that the material consists of gamma iron together with graphite and phosphite. Bearing upon this subject, he has found that the addition of nickel in relatively small quantities, seems to reinforce the action of the silicon and to draw the carbon from the combined to the graphitic state, and this, in his opinion, is the predominating action.

The Heat-Treatment of Nickel Steel

The result of some very complete and interesting work in this field has been published by McWilliam and Barnes.[2] A series of steels was prepared with the nickel content at 3.0 per cent., but with the carbon varying from 0.06 per cent. up to 0.91. The treatment to which 11 inch by 1 inch square bars prepared from 3 inch ingots were subjected, is given along with the essential features of the analyses and heat-treatments in the following table:—

TREATMENT, WITH DISTINGUISHING LETTERS.

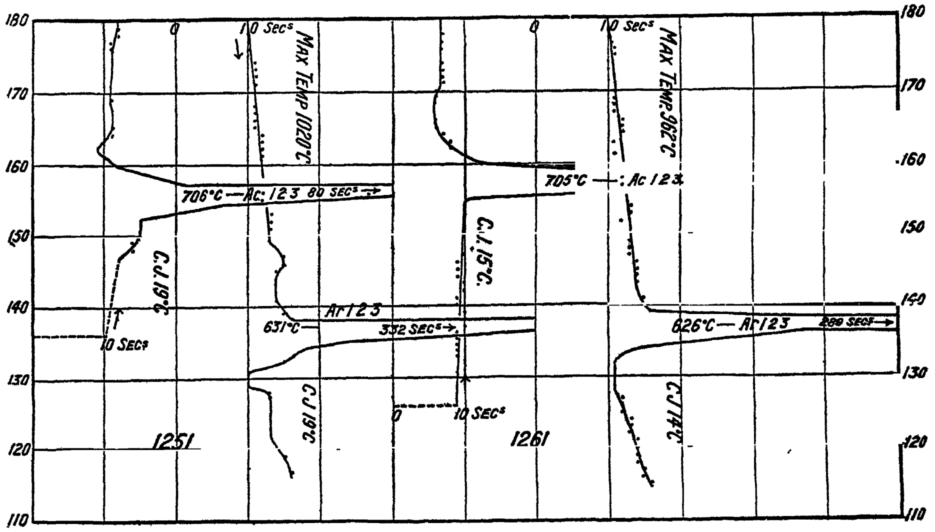
Treatment.	Letter.
As received	None.
Normalized. 900° C. for thirty minutes and cooled in air	N.
Annealed. Slowly heated up to 950° C.; kept at 950° C. for about twenty hours; very slowly cooled down in furnace	A.
Quenched from 850° C. in water and tempered at 400° C.	Y.
" " 850° C. " " 500° C.	X.
" " 850° C. " " 650° C.	T.

[1] Revue de Metallurgie, Vol. V, pp. 306-313.
[2] Journal of the Iron & Steel Institute, May, 1911, No. I, p. 269. See also regarding heat-treatment generally. W. Campbell and H. B. Allen (School of Mines Quarterly, 1911, V. 33, pp. 72 to 83). C. E. Guillaume (Compt. Rend., 1911, V. 153, pp. 156-160).

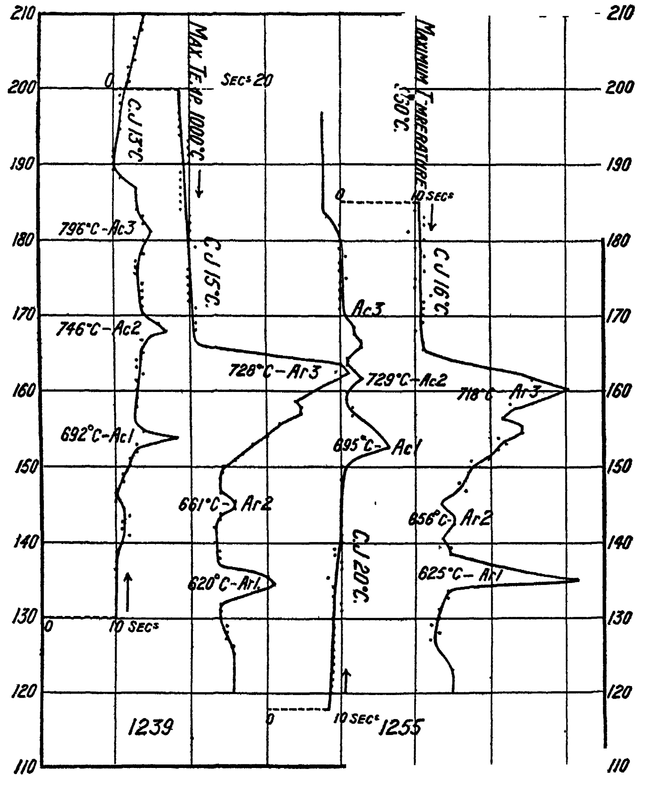
COMPOSITIONS OF THE STEELS

Mark.	Carbon.	Nickel.	Manganese.
	Per Cent.	Per Cent.	Per Cent.
1239	0.06	3.05	0.11
1255	0.12	2.93	0.13
1253	0.28	2.90	0.15
1256	0.30	3.15	0.13
1254	0.47	2.92	0.14
1252	0.67	2.96	0.19
1251	0.74	2.98	0.19
1261	0.91	3.10	0.17

In the normal condition, these alloys, up to the 0.74 per cent. carbon alloy, consist of ferrite and pearlite, the latter constituent progressively increasing with the carbon content; the 0.91 per cent. carbon alloy consists of a matrix of pearlite in which free cementite carbide is beginning to appear. They are comparable with a similar series of carbon steels. Considering first the thermal phenomena, the Ar_3 point in the lowest carbon alloys is exceedingly well developed, and whereas the Ar_2 point is reversible in carbon alloys, it is found, as has already been pointed out, to be distinctly irreversible in the nickel steels. The influence of nickel in depressing the carbon change-point at Ar_1 is confirmed, and it would appear with this percentage of nickel to be firmly fixed in the neighbourhood of 630°C., irrespective of the variation in carbon content. These facts are illustrated in the following curves, and it will be well to bear them in mind when considering the heat-treatment now to be discussed:—



Heating and Cooling Curves of 3 per cent. Nickel Steels, with 0.74 and 0.91 per cent of Carbon respectively



Heating and Cooling Curves of 3 per cent. Nickel Steels, with 0.06 and 0.12 per cent. of Carbon respectively

The first two series of tests obtained by McWilliam and Barnes are on the material in the "as received" and normalized conditions and are given in the following table:—

TREATMENT. AS RECEIVED.

Mark.	Analysis. Carbon per cent.	Analysis. Nickel per cent.	Yield Point. Tons per Sq. In.	Maximum Stress. Tons per Sq. In.	Elongation per cent. on 2 Ins.	Reduction of Area per cent.	$\frac{YP \times 100}{MS}$	Dr. Arnold's Alternating Stress Test.
1239	0·06	3·05	23·0	29·9	35·0	70·6	76·9	189
1255	0·12	2·93	21·0	30·9	34·0	65·8	67·9	259
1253	0·28	2·90	23·0	35·6	29·0	57·7	64·6	300
1256	0·30	3·15	23·0	36·0	28·0	54·6	63·8	301
1254	0·47	2·92	25·0	42·6	22·0	44·6	58·7	267
1252	0·67	2·96	27·0	51·5	19·0	36·7	52·4	248
1251	0·74	2·98	34·0	57·9	14·0	25·2	58·2	218
1261	0·91	3·10	35·0	66·8	8·5	22·1	52·4	188

TREATMENT. NORMALIZED.

Mark.	Analysis. Carbon per cent.	Analysis. Nickel per cent.	Yield Point. Tons per Sq. In.	Maximum Stress. Tons per Sq. In.	Elongation per cent. on 2 Ins.	Reduction of Area per cent.	$\frac{YP \times 100}{MS}$	Dr. Arnold's Alternating Stress Test.
1239 N	0·06	3·05	21·0	29·7	38·0	72·5	70·7	321
1255 N	0·12	2·93	21·2	30·1	36·5	68·4	70·4	319
1253 N	0·28	2·90	23·0	35·0	31·0	59·1	65·7	350
1256 N	0·30	3·15	22·4	36·0	30·0	55·6	62·2	249
1254 N	0·47	2·92	24·8	41·5	23·0	45·9	59·8	278
1252 N	0·67	2·96	29·0	50·7	19·0	37·2	57·2	209
1251 N	0·74	2·98	31·0	59·2	16·0	44·3	52·4	204
1261 N	0·91	3·10	34·0	66·6	12·0	22·7	51·0	149

The striking feature of these results is the low yield points obtained, in comparison with the authors' other series of steels given elsewhere. The next series of tests was upon the annealed bars, and here the disturbing element of precipitated free carbon comes into play. The precipitation had already commenced in the neighbourhood of 0.67 per cent. of carbon, but became accentuated when the carbons of 0.74 and 0.91 per cent. were reached; the latter steels being described as consisting of a ground-work of ferrite containing patches of free carbon, only about 0.10 per cent. of the carbon being retained in the combined condition. These two bars are stated to have black fractures when in this condition. These facts are of considerable interest when the following figures are considered:—

TREATMENT. ANNEALED.

Mark.	Analysis. Carbon per cent.	Analysis. Nickel per cent.	Yield Point. Tons per Sq. In.	Maximum Stress. Tons per Sq. In.	Elongation per cent. on 2 Ins.	Reduction of Area per cent.	$\frac{YP \times 100}{MS}$	Dr. Arnold's Alternating Stress Test.
1239 A	0·06	3·05	18·4	26·8	39·0	71·7	68·7	289
1255 A	0·12	2·93	18·8	27·7	37·0	66·2	67·9	324
1253 A	0·28	2·90	21·2	30·4	31·5	58·2	69·7	220
1256 A	0·30	3·15	16·8	30·0	30·0	54·6	56·0	250
1254 A	0·47	2·92	19·2	32·1	28·0	48·7	59·8	252
1252 A	0·67	2·96	21·2	31·4	20·0	46·0	67·5	198
1251 A	0·74	2·98	16·4	25·0	29·5	46·0	65·6	96
1261 A	0·91	3·10	14·4	23·6	17·0	21·8	61·0	44

The two last test bars in the series are found to give tests more in line with the wrought iron than with high carbon steels. The material was next submitted to the quenching and tempering treatments given on page 392, and the figures obtained on testing the bars so treated, are shown in the following tables:—

TREATMENT Y. 850° C. WATER AND 400° C. AIR.

Mark.	Analysis.		Yield Point. Tons per Sq. In.	Maximum Stress. Tons per Sq. In.	Elongation per cent. on 2 Ins.	Reduction of Area per cent.	YP × 100 / MS	Dr. Arnold's Alternating Stress Test.
	Carbon per cent.	Nickel per cent.						
1239 Y	0·06	3·05	26·4	33·1	37·0	78·4	79·8	286
1255 Y	0·12	2·93	28·0	35·8	34·0	77·4	78·4	295
1253 Y	0·28	2·90	36·8	46·6	27·0	67·4	79·0	308
1256 Y	0·30	3·15	38·4	50·0	24·0	63·5	76·8	307
1254 Y	0·47	2·92	48·8	66·6	18·0	54·6	72·7	214
1252 Y	0·67	2·96	79·4	90·8	13·0	45·1	87·4	184
1251 Y	0·74	2·98	93·2	96·8	10·0	30·3	97·3	118
1261 Y	0·91	3·10	94·0	105·7	8·0	17·6	88·9	...

TREATMENT X. 850° C. WATER AND 500° C. AIR.

1239 X	0·06	3·05	23·2	31·7	37·5	76·8	73·2	283
1255 X	0·12	2·93	25·0	34·4	33·5	76·4	72·7	339
1253 X	0·28	2·90	34·4	45·0	28·5	68·6	76·4	317
1256 X	0·30	3·15	36·0	50·4	24·0	58·4	71·4	320
1254 X	0·47	2·92	42·4	60·4	19·0	53·7	70·2	291
1252 X	0·67	2·96	59·0	74·8	14·5	39·7	78·9	211
1251 X	0·74	2·98	69·0	82·4	12·0	32·9	83.7	116
1261 X	0·91	3·10	73·6	88·9	12·0	30·0	82·8	97

TREATMENT T. 850° C. WATER AND 650° C. AIR.

1239 T	0·06	3·05	23·2	31·1	37·0	77·9	74·6	251
1255 T	0·12	2·93	23·0	32·9	36·0	76·4	69·9	272
1253 T	0·28	2·90	28·4	38·6	33·0	70·8	73·6	268
1256 T	0·30	3·15	29·2	40·2	27·5	63·9	72·6	262
1254 T	0·47	2·92	33·6	47·0	26·0	58·2	71·5	226
1252 T	0·67	2·96	41·0	52·4	21·0	49·0	78·3	143
1251 T	0·74	2·98	46·4	56·2	18·5	43·5	82·6	134
1261 T	0·91	3·10	47·0	57·2	17·0	39·2	80·8	114

One of the steels may be studied in detail with advantage, and for this purpose, No. 1254, containing 0.47 per cent. of carbon and 3.0 per cent. of nickel, may be selected. The results obtained from this particular steel are given in the following table:—

CARBON, 0.47 PER CENT.; NICKEL, 2.92 PER CENT.

Mark	Yield Point. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 ins.	Reduction of area per cent.	YP × 100 / MS	Dr. Arnold's Alternating Stress Test.
1254	25.0	42.6	22.0	44.6	58.7	267
1254 N	24.8	41.5	23.0	45.9	59.8	278
1254 A	19.2	32.1	28.0	48.7	59.8	252
1254 Y	48.8	66.6	18.0	54.6	72.7	214
1254 X	42.4	60.4	19.0	53.7	70.2	291
1254 T	33.6	47.0	26.0	58.2	71.5	226

Some interesting experiments on the heat-treatment of nickel steel, have been made by Fay and Bierer,[1] who treated two open-hearth steels respectively containing 3.15 and 3.5 per cent. of nickel and 0.35 and 0.34 per cent. of carbon. In each experiment, three specimens were placed in the furnace and given the required heat-treatment for a period of two hours. One specimen was oil-quenched, another allowed to cool in air, and a third cooled in the furnace. The oil-quenched specimen was then tempered for two hours at 600°C. In discussing the results, they say that the oil-quenched specimen gave the highest values, both for tenacity and ductility, whilst the next highest values were found in the air-cooled specimen. They considered that the most suitable temperature for the quenching of nickel steels lies between 800° and 850°C., and that, if higher temperatures are used, the structure of the steel "becomes coarser." Bearing on this, it is of interest to note that Heyn and Bauer[2] considered that nickel steel is very apt to split if the forging heat is excessive, pointing out, however, that the exact temperature depends upon the dimensions of the piece and the length of the heating period.

Expansibility

Nickel, when alloyed with iron, exercises more than any other element, a marked influence on the expansion properties of the alloy. C. E. Guillaume,[3] and Charpy and Grenet,[4] in particular, have devoted much study to the peculiar effect of nickel on the co-efficient of expansion of iron and steel.

The following tables show the main results obtained by Charpy and Grenet:—

Coefficients of Expansion of Nickel Steels in the Stable Form and When Cold

Series.	Composition of the Steel.			Mean Co-efficients of Expansion x 10^{-6}.			Remarks.
	Ni.	C	Mn.	From 0 to 200°	From 200 to 400°	From 400 to 600°	
1...	0	0.22	0.48	12	15	15	
	2.05	0.23	0.41	11	14	15	
	8.47	0.25	0.41	14	14	10	
	10.40	0.20	0.44	11.5	11	12	
	21.00	0.36	0.36	10.	10	....	Began to transform at 545°
	26.9	0.35	0.33	7.8	10.5	....	Began to transform at 495°
	29.0	0.35	0.34	12.9	11	....	
2.....	22.8	0.29	0.73	8.5	9	10	
3.....	19.9	0.70	0.48	9	9	....	Began to transform at 560°
4.....	20.75	0.74	0.80	13	16	....	Began to transform at 560°
5.....	20.90	0.97	0.48	12	17	....	Began to transform at 550°

[1] Proc. Amer. Soc. for Testing Materials, 1911, Vol. 11, p. 422.

[2] Mitteilungen aus dem Kgl. Materialprufungsamt, Gross-Lichterfelde, 1910, Vol. 27, p. 1.

[3] "Recherches sur les Alliages de Nickel." Bulletin de la Société d'encouragement pour l'industrie Nationale, 1901. Les applications des aciers au Nickel. Paris, 212 pp Les aciers au Nickel et leurs applications a l'Horologie. Paris, 54 pp.

[4] "Recherches sur la Dilatation des Aciers aux Temperatures Elevées." Bulletin de la Société d'encouragement pour l'industrie Nationale, 1903, p. 464.

Coefficients of Expansion of Nickel Steels in the Stable Form and When Hot

Series.	Composition of the Steel.			Mean Co-efficients of Expansion.			
	Ni.	C.	Mn.	From 0 to 200°	From 200 to 400°	From 400 to 600°	From 600 to 900°
1	2.01	0.21	0.41	....	....	....	23×10^{-6}
	8.47	0.25	0.41	....	....	16×10^{-6}	21
	10.47	0.20	0.41	....	....	20	22.5
	21	0.36	0.36	....	17×10^{-6}	20	20
	26.90	0.35	0.36	16.2×10^{-6}	20	18.6	22.1
	29.00	0.35	0.34	12.5	17.5	19	18.5
	31.35	0.36	0.37	6.5	15	17	18.3
	34.75	0.36	0.36	3.5	13.5	17	17.5
	36.05	0.39	0.36	1.0	6.2	17.5	19
2	22.8	0.29	0.73	22	20	17	20
	32.8	0.29	0.66	11	17.5	20.5	20
	35.8	0.31	0.69	2.5	12.5	18	19
	37.4	0.30	0.69	2.5	8.5	19	17
3	19.9	0.70	0.48	23	20	18.5	29
	24.6	0.78	0.45	16	20	19	30
	25.0	0.84	0.48	15	19	20	28
	28.8	0.78	0.48	10.5	18	19	26
	34.3	0.70	0.45	2.5	13.5	17	25
	34.8	0.63	0.49	2.5	10	18	23
4	20.75	0.72	0.80	22	20	20	28
	26.20	0.71	0.90	15	20	20	29
	29.40	0.73	0.90	16	19	20	27
	34.45	0.77	0.90	3	15	16	24
	35.35	0.71	0.89	2.3	13	16	24
5	20.9	0.97	0.48	....	20	27	27
	29.9	0.89	0.43	12	19	18	28
6	21.25	0.92	0.97	....	15	18	32
	25.40	1.01	0.79	15	20	20	32
	29.45	0.99	0.89	11	19	20	29
	34.5	0.97	0.84	3	13	18	25

High-Nickel Steels

The result of the work of the above and many other observers, but especially of Guillaume, has been the introduction of a large number of steels high in nickel contents, which, although they have not yet led to a great increase in the weight of the nickel used, and are scarcely likely to do so, have introduced a number of uses for nickel which may ultimately be of as far reaching importance as the use of tungsten in electric lamp filaments, where the weight of metal used is negligible as a percentage of the total, although the saving to the world is measured in millions.

As these high-nickel steels are not only remarkable for their properties as to expansibility, but also as to magnetization and resistance to corrosion, the following notes on the history and qualities of these special alloys have been collected here instead of adopting the more correct, but less convenient, system of distributing them under the special headings dealing with their properties.

Following the work of Riley (1889), Professor Hopkinson, in the same year, discovered that the 25 per cent. nickel steel was practically non-magnetizable at ordinary temperatures and, in a paper read next year before the Royal Society,[1] described the effect of heat treatment, including its effect on nickel steel wire as regards magnetic permeability, electrical resistance, and mechanical properties. He followed the above by another paper in the same year and a third in 1891; and the following decade, largely due to his initiative, was rich in papers dealing with the properties of nickel steels, and especially with those of high tenor in nickel, not only by scientists such as Guillaume, Osmond and Dumas, but by large engineering firms and corporations such as Hadfields, Vicars, Cammell (now Cammell, Laird & Company), of England, La Société de Commentry-Fourchambault of France, the Bethlehem Steel Works (then the Bethlehem Iron Company) of the United States, the International Bureau of Weights and Measures, the United States Navy and Ordnance Departments, the British Admiralty, the Russian Navy Board, and the German military authorities. This work was mainly centred round the ordinary nickel steel containing under 5 per cent. of nickel. Natural and ordinary heat-treated steels were compared with Harveyized steels, and with special steels then in use for offensive and defensive war purposes. The results of the work of these authorities have been quoted very fully in the first three Annual Reports of the Ontario Bureau of Mines (1891 to 1893), where full references to original sources of information will be found.

As regards the high-nickel steels, the following are sold under special names, but a large variety are made which yield almost any required expansibility, any desired magnetic permeability within possible limits, and a large range of electrical resistance for use in general electrical and electric furnace work:—

Invar

"Invar" contains about 36 per cent. of nickel, with 0.5 per cent. of manganese and 0.5 per cent. of carbon. It melts at 1,425°C., can be forged, drawn and worked readily, and takes a fine polish which makes it highly suitable for graduation. It is very ductile and strong, and highly resistant to corrosion. This alloy has practically no coefficient of expansion (less than one-fifteenth of that of steel, and about one-tenth of that of platinum) between minus 100° and plus 150°C., and is practically non-corrodible. It is largely used in the manufacture of measuring and other philosophical instruments, and for chronometers and other clockwork, and for special purposes is "aged," i.e., kept for some years under special conditions which render it more reliable as to regularity of change in volume with change of temperature.

Platinite

"Platinite" contains about 46 per cent. of nickel and about 0.15 per cent. of carbon, and has the same expansion as platinum. It or other nickel steel of about the same composition is used in place of platinum, for sealing into glass as the leading-in wires of electric lamps. It is stated that a compound wire with a 38 per cent. nickel steel core encased in copper and sometimes coated with platinum, is now used in preference for that purpose. "Platinite" and "dilver," a very simi-

[1] Proc. R. Soc. 1890. V. 48.

lar alloy, are also used for the delicate mountings of special lenses to avoid the risk of optical strain upon the lens with change of temperature. "Ferro-nickel" is a term frequently applied to nickel steel containing 25 per cent. of nickel, and largely used in the construction of rheostats and as a general electrical resistance wire.

An alloy containing 56 per cent. of nickel, is used in the construction of industrial measuring machines, on account of its being more stable and less corrodible than ordinary steel, but having about the same thermal expansibility as that metal.

As an indication of the extreme range covered by steels containing nickel, Circular No. 58 of the U. S. Bureau of Standards[1] may be quoted. It gives a list of firms who make these special steels, and states that steels containing from 1.5 to 95 per cent. nickel are manufactured in the United States for a great variety of purposes, e.g., gun tubes and other gun parts, pneumatic hammers and air drills, turbine blades, gas-engine valves, ignition tubes, spark plugs, axles, shafts, steering knuckles, gears, and other parts of automobiles, aeroplanes, and machinery subjected to severe stresses.

13 Per Cent. Nickel Steel

The following particulars are quoted from H. D. Hibbard:—[2]

Before Arnold and Read's discovery[3] of the 13 per cent. grade, 15 per cent. nickel steel was thought to have the greatest strength of all the nickel steels—that is, in the natural state. This variety has been employed in a few instances for shafting and similar service for which other steels failed, but the amount of it used is negligible in statistics. It is hard to machine, and heating followed by slow cooling does not soften it, though heating and quenching does enough to allow it to be machined slowly. It has a tensility of about 170,000 pounds and an elastic limit of 150,000 pounds per square inch, according to one observer, though, as stated above, Hadfield obtained 210,560 pounds tensility, with little ductility. It is likely that the properties desired when this steel was used, particularly its ductility, could now be surpassed by the much cheaper heat-treated ordinary nickel or nickel-chromium steels.

Eighteen per cent nickel-iron alloy, although not useful, is worthy of note here because of its anomalous action[4] when cooled from 200° C. (392° F.). At first it contracts uniformly until its temperature falls to 130° C. (266° F.). Then it expands while cooling to 60° C. (140° F.), when it again contracts as the temperature falls farther.

Twenty-two per cent. nickel steel is used when resistance to rusting or corrosion is desired. A noted example is the valve stems of the salt-water fire-protection service of the city of New York, where the apparatus may not be allowed to become inoperative or hard of action from the formation of rust. It is also used sometimes for the spark poles in the spark plugs of internal-combustion engines, including automobiles, though commercial nickel wire is more commonly used.

High-nickel steels having 25 per cent. or more of nickel and low carbon content are austenitic in structure, and in the natural state are softer and tougher than the medium-nickel martensitic steels.

High-nickel steel containing 24 to 32 per cent. nickel in the form of wire is used for electrical resistance in small quantity, probably between 5 and 10 tons per year in this country.

Resistance Wire

The analysis and resistance of samples of Krupp nickel steel resistance wire are shown on following page. This wire is used in electric toasters, cookers, irons, and similar devices.

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[1] Invar and Related Nickel Steels, p. 60.

[2] Manufacture and Uses of Alloy Steels, U. S. Bureau of Mines. Bulletin 100. 1916.

[3] Proc. Inst. Mech. Engineers. 1914.

[4] Sexton, A. H., and Primrose, J. S., The Metallurgy of Iron.

Analysis and Resistance of Samples of Krupp Nickel Steel Resistance Wire.

Sample No.	C.	Mn.	Si.	S.	P.	Cr.	Ni.	Specific resistance per cubic centimeter
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Microhms.
1	0.52	0.75	0.10	0.035	0.024	....	30.6	87.9
2	0.39	1.00	0.70	0.035	·0.025	....	24.2	....

D. H. Brown[1] says:—

"Tico" resistance-wire, made by the Trenton Iron Company, and containing about 28 per cent. of nickel, is largely used for resistance-coils in rheostats and electrical heaters. It has considerable advantage over German silver in having three times as much resistance, and retaining its strength and elasticity even after heating to bright redness. No. 14 B. & S. Tico wire averages 8 feet to the ohm of resistance; the same size of German silver wire requires in practice 25 feet to the ohm.

A similar resistance-wire, known as "Climax" wire, containing about 24 per cent. of nickel, is made by Roebling's Sons Co. This wire has a specific gravity of 8.137, a resistance per mill-foot at 75° of 504.86 ohms, and a temperature coefficient of 0.042 per cent. per degree F.

Another nickel-iron resistance-wire, made in Germany, and containing about 29 per cent. of nickel, has specific gravity 8.4; specific resistance at 20° C. (68° F.) of 86 microhms; a coefficient of temperature of 0.00065 for 1° C., and a resistance per mill-foot of 517.5 ohms.

The specific resistance of German silver is on the average at 20° Centigrade, 31.5 microhms.

Owing to their high percentage of nickel, these wires are nearly incorrodible, and, owing to their high tensile strength, they are much less liable to break than German silver. After repeated heating and cooling, German silver becomes brittle, while nickel-iron alloys seem to retain their original elasticity.

The results of the measurement of the thermo-electromotive force of certain iron alloys against copper for the interval 0°—100° C. are given in millivolts in the following table[2]:—

Thermo-Electromotive Force of Some Iron Alloys

Iron-Nickel			Iron-Chromium			Iron-Cobalt		
Fe.	Ni.	E.M.F.	Fe.	Cr.	E.M.F.	Fe.	Co.	E.M.F.
100	....	+0.86	90	10	1.20	90	10	—0.64
83	17	—0.64	82	18	1.04	80	20	—3.70
80	20	—0.55	80	20	0.43	70	30	—3.50
70	30	—0.52	76.5	23.5	8.32			
18.8	81.2	—2.45						
7	93	—1.90	70.5	29.5	0.31			
....	100	—2.38						

[1] Nickel Steel, a Synopsis of Experiment and Opinion. Trans. Am. Inst. M E, 1899, p. 72.
[2] T. S. Fuller, Amer. Electrochem. Soc., April, 1915. Met. and Chem. Eng, 1915, 13, 318—319.

Thermo-Electromotive Force of Some Iron Alloys (*Continued*)

Iron-Nickel-Chromium				Iron-Nickel-Manganese			
Fe.	Ni.	Cr.	E.M.F.	Fe.	Ni.	Mn.	E.M.F.
79	17	4	—0.12	87	10	3	—1.09
70	20	10	—0.46	86	12	2	—1.02
35	55	10	0.00	81	17	2	—1.50
25	60	15	0.07	80	17	3	—0.79
25	50	20	0.07	76.5	17.5	6	—0.73
20	55	25	—0.08	76	22	2	—1.84
4	89.6	5.65	1.70	50	44	6	—0.59

Steel with 27 per cent. of nickel is used in bits, stirrups and spurs in riding harness, because of its resistance to rusting. It will nevertheless rust slowly at ordinary temperature under conditions that strongly induce oxidation.

Non-Magnetic Property of High-Nickel Steel

Steels containing more than 24 per cent. of nickel are practically non-magnetic in their ordinary condition, a rather remarkable fact, when the high magnetic susceptibility of both iron and nickel alone is considered. The explanation that the critical point marking the change from the non-magnetic to the magnetic state of iron is lowered by the nickel from about 700° C. (1,292° F) to below ordinary atmospheric temperatures is, no doubt, sound as far as it goes. When 25 per cent. nickel steel is cooled to minus 40° C. (minus 40° F.) it becomes magnetic, and retains its magnetism at ordinary atmospheric temperatures. On being heated to 580° C. (1,076° F.), however, the alloy reverts to the non-magnetic state. This separation of 620° C. between the critical points marking the magnetic states in heating and cooling is great in comparison with the 25° to 50° C. of simple steels, and because of it this steel is classed as irreversible. The non-magnetic quality of high-nickel steel is not utilized, chiefly because of its capacity for becoming magnetic, as described above, for if the steel happened to be cooled enough to make it magnetic, it could not in most cases be easily demagnetized.

The fact that high-nickel austenitic steels have a somewhat lower modulus of elasticity than the low-nickel or simple steels, does not affect their value for the uses made of them. These steels also have low elastic limits, though they are tough and show up well in the shock test. Nevertheless they are generally used, not because of superior physical properties, but because of their resistance to rusting and corrosion or their electrical resistance. With a carbon content of 0.25 to 0.30 per cent. and 32 per. cent. nickel, they are used in valves for gasoline motors with good results.

Nickel steel with 30 per cent. of nickel is used in boiler tubes, particularly in marine boilers, for which it is admirable. These tubes are in the natural, not heat-treated state. They resist corrosion better than simple steel tubes and last three times as long.

Complex Nickel Steels and Alloys used in their Manufacture

In addition to the nickel-chromium, nickel-copper and other special steels referred to under their appropriate headings in this Chapter, a considerable variety of steels containing other metals such as vanadium, tungsten, molybdenum and titanium are in use for special purposes. Many possess distinct and fully recognized advantages, but a large number are merely the subject of patents or of unproved claims, and it has not been thought advisable to deal with them in this report, on account of the small amount of nickel which they represent, and the doubt as to the future of a considerable proportion of them. It is, however, noticeable that the names of many important armament and other firms in England, Europe and the States figure among the patentees.

The alloys used in the manufacture of these and other nickel steels are, however, of considerable interest and importance, and the following analyses may be taken as typical of those in use at the present time:—

Ferro-Nickel

Ferro-nickel commonly contains 25, 35, 50 or 75 per cent. of nickel, the balance outside the nickel and iron being about:—

	Per cent.
Carbon	0.85
Silicon	0.25
Sulphur	0.015
Phosphorus	0.025

Ferro-Nickel Chrome

Carbon.	Chromium.	Nickel.	Iron.
0.25 to 0.75	51 to 52	17 to 19	29 to 30
1.30 to 1.80	50 to 51	17 to 19	28 to 29

Ferro-Nickel Silicon

Ni	Si.	Al.	Mn.	Ca.	Mg.	P.	Cu.	Fe. (by difference)
30.00	47 20	2.90	0.90	0.15	0.57	0.02	2.58	15 68

Nickel-Chromium

C.	Cr.	Ni.	Si.
1.00	72 to 75	23 or 24	0 25

Nickel-Tungsten

C.	W.	Ni.	Si.
0.5 to 1.0	50.0 to 75.0	25.0 to 50.0	0.25 to 0.50

Nickel-Molybdenum

C.	Mo.	Ni.	Si.
0.5 to 1.0	50.0 to 70.0	30.0 to 50.0	0.25 to 0.50

Nickel-Manganese Steel

According to E. C. Harder[1] nickel-manganese steels are structurally, i.e., microscopically, similar to nickel steels, and may often be substituted for them as being cheaper. He does not, however, state the percentage of nickel or of manganese to be used.

Resistance of Nickel Steels to Corrosion

The resistance to corrosion of steel induced by the addition of nickel with or without chromium, copper or other metal, has been referred to elsewhere in this section, and has been the subject of much unsettled controversy, although the fact of such improvement, whatever its actual amount may be, is admitted. The matter has been recently discussed in the transactions of the Faraday Society,[2] and by Friend, Bentley and West,[3] and in a recent publication of the United States Bureau of Standards.[4] The corrosion with ordinary fresh water, sea water, and acid liquors, decreases as the percentage of nickel increases, and it is stated that the alloy containing 18 per cent. of nickel may be regarded as practically non-corrodible.

The steels containing still more nickel, such as invar (36 per cent. nickel) are of especial importance in this connection, as they are largely and increasingly used for philosophical instruments, measuring tapes, etc., and it is found that, although it is advisable, as recommended by the Bureau of Standards, to coat an invar instrument with vaseline when likely to be long exposed to a moist atmosphere, this is probably the most resistant of all steels to the danger of rusting.

From the tests reported by Friend, Bentley and West,[5] it would appear that the beneficial effects of nickel has not been proved so markedly in long-exposure tests as might have been expected from tests of shorter duration. The results of tests on ordinary copper-steels which are of interest also in connection with nickel-copper steels, will be found in the papers and circulars mentioned in the footnote.[6]

The Uses of Nickel Steels

References to most of the principal uses of both ordinary and special nickel steels will be found throughout this section, together with analyses and figures as to the mechanical properties of the principal types.

The term nickel steel should properly be taken to refer only to the ordinary, low-carbon steels carrying about 3½ per cent. of nickel, but it is commonly used indiscriminately for such and other ordinary nickel steel, nickel-chromium steel and the many varieties containing also rare metals such as vanadium, etc.

[1] Manganese Deposits of the United States, etc. Bulletin 427 (1910) of the U. S. Geological Survey, p. 256.

[2] Vol. II, April, 1916, pages 212 to 234.

[3] Trans. Iron and Steel Inst., May, 1912, and Proceedings Inst. of Metals, 1913.

[4] Circular No. 58, April, 1916. Invar and Related Nickel Steels.

[5] L. c.

[6] D. M. Buck, "Keystone Copper-Bearing Steel," "Copper in Steel," American Chem. Soc., March 25, 1913, and "Recent Progress in Corrosion Resistance," American Iron and Steel Institute, May, 1915; also D. M. Buck and J. O. Handy, "Research on the Corrosion Resistance of Copper Steel" (Am. Sheet & Tinplate Co., Pittsburgh), and E. A. and L. T. Richardson, "Observations on the Atmospheric Corrosion of Commercial Sheet Iron, Particularly in Regard to the Influence of Copper and Mill Scale," American Electro-Chemical Society, September, 1916.

The nickel steel industry probably uses up nearly three quarters of the total nickel production under present war conditions, and between half and two-thirds in normal times.

The largest tonnage is used for defensive and offensive war purposes, and for structural steel, but no less important to the world at large, although smaller as to quantity, is the use for automobile and aeroplane parts, and the innumerable constructional steel parts where weight or bulk must be kept down to the lowest possible limit.

Among the principal uses, may be mentioned bridge building, locomotive and other railway plant, marine and stationary engines, electrical plant, turbines, etc.

In Great Britain, the larger proportion of the large steel firms are now making or using nickel steel, largely for projectiles and guns, gun shields and armour plate. In the United States, among other firms, the Carnegie Steel Company and the Carbon Steel Company are large manufacturers of armour plate, the Midvale Steel Company and the Bethlehem Steel Company of armour, guns and projectiles, and the Carpenter Steel Company and the Crucible Steel Company, of projectiles.

Of the total steel business done by the above mentioned companies, the percentage of nickel steel business, although important, is small.

F. Bohny[1] states that, in Germany, the use of nickel steel for bridge building was first proposed by the Gutehoffnungshutte at Oberhausen, Germany, in the autumn of 1908. The first work undertaken was a small railway bridge near Oberhausen of 31.5 metres length between supports, which was constructed entirely of nickel steel. Nickel steel has also been employed in the construction of a suspension ferry over the entrance to the harbour at the Imperial Dockyard, Kiel, and of a covered foot-bridge over the Rhine-Herne canal. The German company above mentioned make a steel containing 2 to 2.5 per cent. of nickel, with a strength of 35.5 to 41 tons per square inch. The permissible stress on the structure is 60 per cent. higher than that for ordinary structural steel.

Large quantities have also been used in the Manhattan and Queensborough bridges, New York City, the St. Louis Municipal bridge over the Mississippi, and the Kansas City viaduct and bridge over the Missouri, and for the emergency dam, locks and spillway of the Panama Canal.

In connection with the use of nickel steel for the Quebec bridge, it is stated by Modjeski[2] that the theoretical limit for a simple truss bridge span in ordinary carbon steel as compared with nickel steel is as 20 to 27, from which it would appear that the use of the latter would deduct about one-third from the weight for equal strength, or add correspondingly to the strength for equal weight, and might result in a saving in actual cost in addition to permitting the construction of structures which could not be made with ordinary steel.

It has been estimated by another authority that, for bridges and similar structural work, the saving in weight may be from 10 to 30 per cent. and in cost, up to 12 per cent., the latter being due, of course, to the less weight of steel used notwithstanding the higher cost for weight.

[1] Stahl und Eisen, 1911, Vol. 31, pp. 89 and 184.
[2] Engineering, Sept. 18, 1914, p. 350.

According to D. H. Browne,[1] if nickel costs 33 to 36 cents per pound,—each per cent. of nickel adds one-third of a cent to the cost of a pound of steel; so that three per cent. nickel steel will cost one cent more per pound than ordinary steel.

The uses of the high-nickel steels have been dealt with in other parts of this section as regards electrical resistance, expansion and resistance to corrosion.

It is a curious fact that, although cobalt is an essential constituent of well-known high-speed tool steels, such as the American "stellite" and the German "iridium steel," nickel does not appear to have been employed to any extent in their manufacture. A series of 26 analyses of American, English and German high-speed tool steels tabulated by H. D. Hibbard[2] does not show one containing more than what may be described as a trace of nickel. A special tool steel called "reactol[3]" is, however, stated in a private communication from the agents to the Commission, to contain nearly two-thirds of nickel. Its composition was not stated except that it contained neither tungsten, molybdenum, vanadium nor cobalt.

Increasing Use of Nickel-Chromium Steel

Reference has been frequently made elsewhere in this Chapter to the constitution, properties, and uses of this alloy, and the phenomenal increase in its use has been emphasized. Nickel-chromium steel is the most important of the alloy steels used for structural purposes, as the tonnage used now far exceeds that of ordinary nickel steel. It is made by 10 or 12 companies in the United States, where, according to Hibbard[4] the production in 1913 was about 100,000 tons of ingots, all made in the open hearth with the exception of 2,000 to 3,000 tons from crucibles and electric furnaces. A letter from the Director of the Department of Commerce (Bureau of the Census, U. S.) to the Commission, dated Oct., 1916, states that the output of nickel steels in 1914 was as follows:—

Nickel steel	69,955 tons.
" chrome steel	102,562 "
" " vanadium steel	14,123 "
" " titanium steel	1,106 "

It is interesting to compare these figures with the following figures received by the Commission from the American Iron and Steel Institute showing the production in 1910:—

——	Ingots. tons.	Per cent.	Castings. tons.	Per cent.	Total. tons.	Per cent.
Total alloy steel	538,462	....	29,357	....	567,819	....
Total steel	25,154,087	....	940,832	....	26,094,919	....
Nickel steel	102,430	66.53	4,277	89.63	106,707	67.23
Nickel-chrome steel	51,526	33.47	495	10.37	52,021	32.77
	153,956	100.00	4,772	100.00	158,728	100.00

[1] Nickel Steel, a Synopsis of Experiment and Opinion, 1899, p. 75.
[2] Manufacture and Uses of Alloy Steels, U. S. Bureau of Mines, 1916, p. 57.
[3] Machinery (London), June 22, 1916, p. 364.
[4] Manufacture and Uses of Alloy Steels, U. S. Bureau of Mines, 1916, p. 46.

The following comparative figures have been calculated out from these:—

Proportion of Nickel and Nickel-Chrome Steel to Total Alloy Steel and Total Steel

—	Total Alloy Steel.			Total Steel.		
	Ingots. p.c.	Castings. p.c.	Total. p.c.	Ingots. p.c.	Castings. p.c.	Total. p.c.
Nickel steel	19.0	7.5	18.79	.407	.455	.408
Nickel-chrome steel	9.1	5.9	9.16	.204	.053	.199
	28.1	13.4	27.95	.611	.508	.607

It will be noted that, in six years, the positions of nickel steel and nickel-chromium steel have become practically reversed. The latter is easier to make and is naturally cheaper, as it commonly contains less nickel. The maximum for nickel in a nickel-chromium steel is about 3.5 per cent., the usual proportion being much less, and the chromium commonly less than half the nickel. According to Guillet[1], case-hardening is more effective with nickel-chromium than nickel steels. Chromium increases the resistance of nickel steel to wear. It is mainly used for armour-plate and for projectiles and for automobile parts. Hibbard[2] states that three grades of nickel-chromium steels, known as low, medium and high, are used for automobiles. The carbon content may be varied for each grade within the following limits:—

Composition of Nickel-Chromium Automobile Steels

Grade.	C.	Mn.	Si.	S.	P.	Ni.	Cr.
Low..................	0.20 to 0.40	0.65	Low	0.045	0.04	1.25	0.6
Medium	0.20 to 0.40	0.65	Low	0.045	0.04	1.75	1.10
High	0.20 to 0.40	0.65	Low	0.045	0.04	3.50	1.50

These steels are almost invariably heat-treated for use in automobiles, a wide range of properties being attainable by varying the heat treatment with each steel. The properties overlap those of steels of both harder and softer grades, so that a wide choice of properties is afforded as well as a choice of steels for the set of properties desired.

Use in Armour-Plate and Projectiles

An important use for chrome-nickel steel is in both thick and medium armour plate for war vessels. The thick heavy side armour, 6 to 14 inches thick, is face-

[1] Rev. de Metallurgie, 1906, part 3. See also Comptes Rend., 1913, v. 156, p. 1774 to 1776, and 1914, v. 158, p. 412 to 414.
[2] L. c.

hardened by the well-known methods. A recent analysis of the body of a plate gave: C, 0.33 per cent., Mn, 0.32 per cent., Si, 0.06 per cent., S, 0.03 per cent., P, 0.014 per cent., Ni, 4 per cent., Cr, 2 per cent., and its tensile properties after treatment were

Tensile strength, pounds per square inch	101,000
Elastic limit, pounds per square inch	77,500
Elongation in 2 inches, per cent	24
Contraction of area, per cent.	60

Medium armour, between 3 and 5 inches thick, is not face hardened, but is given high properties as a whole by the heat treatment to which it is subjected. A recent analysis showed: C, 0.30 per cent., Mn, 0.34 per cent., Si, 0.13 per cent., S, 0.03 per cent., P, 0.03 per cent., Ni, 3.66 per cent., Cr, 1.45 per cent.

Its physical properties were those given below as sample 1. Sample 2 represented another chrome-nickel steel made for the same purpose, containing 3½ per cent. of nickel.

	Sample 1.	Sample 2.
Tensile strength, pounds per square inch	119,000	138,000
Elastic limit, pounds per square inch	106,000	119,000
Elongation in 2 inches, per cent.	22	22
Contraction of area, per cent.	61	49

Such steel is most excellent for use on warships to form protective decks and barriers to protect from secondary battery fire. Chrome-nickel-vanadium steel is also used for this purpose.

Nickel-chromium steel is used in the manufacture of most armour-piercing projectiles.

Cubillo[1] cites a steel for projectiles, having C, 0.48 per cent., Mn, 0.58 per cent., Cr, 0.75 per cent., Ni, 2.55 per cent., Si, 0.40 per cent., P, 0.04 per cent. A test piece quenched in oil and tempered, had an elastic limit of 129,400 pounds per square inch, a tensile strength of 150,300 pounds per square inch and an elongation of 19 per cent.

For large projectiles, Girod[2] prefers chromium-tungsten steel having C, 0.50 per cent., Ni, 4 per cent., Cr, 0 to 1.5 per cent., and W, 0.25 per cent.

Chromium in Ordinary and Complex Nickel Steels

The following particulars and opinions on ordinary nickel-chromium and ordinary nickel steels, and on some of the more complex steels containing nickel and chromium, are taken from E. F. Law's Alloys and their Industrial Application (1909 edition.) :—

The influence of chromium on steel is somewhat different from that of nickel and manganese. It appears to raise slightly the point of Ar, but according to Osmond, the point of magnetic transformation is only slightly affected.

As regards the constitution of the chromium steels, those containing less than 7 per cent. of chromium are pearlitic, and those containing from 7 to about 15 per cent. are martensitic. With more than 15 per cent. a double carbide makes its appearance in the form of small particles, which are perfectly white and very hard. As in the case of nickel and manganese steels, these changes occur with smaller percentages of the metal, when the carbon content is higher and the martensite tends to alter into troostite. In the alloy, containing 0.8 per

[1] Armour-Piercing Projectiles: Journ Iron and Steel Inst., 1913, p. 251.

[2] Discussion of Paper on Armour-Piercing Projectiles: Journ. Iron and Steel Inst., 1913, p. 252.

cent. of carbon, the structure ceases to be pearlitic with 3 per cent. of chromium. The pearlitic steels are stronger and harder than the corresponding carbon steels, but somewhat more brittle. Those possessing a martensitic structure are extremely hard and give high tensile tests, but are not so brittle as might be expected until the chromium present is sufficient to produce a double carbide. When an appreciable quantity of this constituent is present, the alloys give low tensile tests and good elongations, as in the case of the crystalline alloys of nickel and manganese, but, unlike these alloys, they are very brittle on account of the presence of the double carbide.

As regards heat treatment, the pearlitic steels are converted into the hard martensitic variety by quenching, and the martensitic and carbide steels are slightly softened by the same treatment. Only the pearlitic steels are of any industrial value. They are largely used as tool-steels, and also for armour plates and armour-piercing projectiles. The steel used in the manufacture of projectiles contains about 1 per cent. of carbon and 2 to 3 per cent. of chromium. Chromium is also occasionally added to steel intended for springs and tyres, and is frequently a constituent of high-class file-steels.

In addition to the ternary steels just described, a large number of quaternary, or even more complex, steels, are in use at the present time. Their constitution is in every way comparable with the ternary alloys, and not more complicated. By adding two or more metals, however, it is often possible to obtain a steel combining the useful properties conferred by each of the added metals singly.

The more important of the quaternary steels are the nickel-chromium, chromium-tungsten, and manganese-silicon, while the nickel-vanadium, chrome-vanadium, and nickel-tungsten appear to possess properties which should ensure for them a successful future. Among the more complex steels, may be mentioned the chrome-tungsten-molybdenum steels, which, in the form of tools, may be used at a speed which maintains them at a red heat without suffering any serious deterioration.

As regards the application of the quaternary steels mentioned above, the nickel-chrome steels are used for armour plates and armour-piercing projectiles, as well as for the shafts and gearing of motors. The composition of the steels employed for these purposes, is as follows:—

	C	Ni.	Cr.
Armour plates	0.2 to 0.5	2.0 to 2.5	0.2 to 0.8
Projectiles	0.8	2	2
Shafts, gearing, etc.	0.2 to 0.5	2 5	0.25 to 0.5

These figures may be compared with those previously quoted from Hibbard and in the specifications already given, and with the following statement and analyses by L. G. L. Norris:—[1]

The addition of chromium to nickel steels greatly increases their strength and resistance to shock, and particularly the mineralogical hardness. The steels become more difficult to forge and heat-treat and harder to machine, and are also liable to the seaminess frequently present in nickel steel. There are three types of these steels, differing both in the percentage of nickel and chromium, and all with low or medium carbon:

	Nickel.	Chromium.	Carbon.
1	3.5 per cent.	1.50 per cent.	0.25 to 0.45 per cent.
2	2.0 per cent.	1.00 per cent,	0.10 to 0.45 per cent.
3	1.5 per cent.	0.50 per cent.	0.10 to 0.45 per cent.

The first type is used principally for armour plate and armour-piercing projectiles and came into use about 1895, superseding the nickel plates and chromium projectiles. The other two types were developed by the automobile industry. The second type is largely employed for automobile forgings. It gives high strength with heat-treatment, has great hardness, and good shock and fatigue-resisting qualities. The third type is an all-round engineering steel, largely used for automobile forgings, and for a variety of miscellaneous drop forgings and machine parts. It is an excellent case-hardening steel, carburizing readily. This type is more tractable in working, heat-treating and machining than the other two, but is somewhat lower in tensile strength.

[1] Can. Min. Journal, Jan. 15, 1916, p. 44.

"Natural" Nickel and Nickel-Chromium Steels

The existence of enormous deposits of nickeliferous iron ores in Cuba and Greece, and in the island of Seboekoe near Borneo, is of interest in connection with the use of low nickel steels, especially those containing chromium. The fact that nickeliferous pig and steel are produced from them, has a special bearing on the question of manufacturing nickel-copper steel direct from the Sudbury nickel ore.

The composition of these ores is given in Chapter IV dealing with Ore Deposits, where figures are given showing the quantity of Cuban ore exported to the United States during the time the deposits have been under operation. The proportion of nickel which these undoubtedly large and important deposits contain is also dealt with, and the Seboekoe ores, of somewhat similar origin and character, are described.

A large amount of material has been published in connection with the Cuban ore and the pig and steels made from it, and also from the Grecian ore.[1]

Nickel-Chrome Ores of Cuba

The Cuban ore contains a large excess of alumina, and is commonly smelted with about one-third its weight of Daiquiri ore, which contains very little alumina, and with dolomitic and other limestone. The excess of chromium is expelled in the slag in the open hearth furnace, reducing that element below the maximum permissible in conjuction with the 1 per cent. to 1½ per cent. of nickel commonly present in the pig or steel.

The following analyses of the materials used in making Mayari pig iron and of the pig itself and resulting steel are taken from figures given by Mr. Quincy Bent and others:—[2]

Nodulized Mayari iron ore: Fe, 54.98; SiO_2 3.45; Al_2O_3 14.00; S. 0.11; P. 0.020; Mn. 0.85; Cr. 2.03; Ni. 1.00; C. 0.19; moisture 2.70; TiO_2 0.60; V. trace.

Daiquiri iron ore: Fe. 58.00; SiO_2 10.69; Al_2O_3 1.08; S. 0.52; P. 0.025; Mn. 0.24; moisture 1.56.

Coke: Volatile matter 1.00; fixed carbon 87.50; ash 11.00; S. 1.10; P. 0.010; H_2O 6.00.

Limestone: $CaCO_3$ 93.50; SiO_2 2.00; Al_2O_3 0.45; Fe_2O_3 0.40; $MgCO_3$ 2.50.

Dolomite: $CaCO_3$ 53.13; SiO_2 2.25; Al_2O_3 0.55; Fe_2O_3 0.60; $MgCO_3$ 42.00.

Slag: SiO_2 22.50; Al_2O_3 29.40; CaO 36.10; MgO 9.50; S. 1.90.

Pig iron: Fe. 90.73; C. 4.25; Si. 0 85; P. 0.050; S. 0.025; Mn. 1.00; Cr. 2.00; Ni. 1.00; Ti. 0.10.

Bessemer rail steel; C. 0.45; Mn. 0.90; Cr. 0.20; Ni. 1.00.

Open-hearth rail steel: C. 0.65; Mn. 0.75; Cr. 0.20; Ni. 1.00.

Duplex metal: C. 1.00; Mn. 0.15; P. 0.05; S. 0.05; Si. nil; Cr 0.30; Ni. 1.00; Fe. 97.45.

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[1] Quincy Bent, Pittsburgh Meeting Iron and Steel Institute, Oct. 25, 1912, Iron Age, Oct. 31, 1912, p. 1028 to 1031, and Aug. 19, 1915, p. 416. "The Use of Mayari Iron in Foundry Mixtures" and "Mayari Steel," two pamphlets issued by the Pennsylvania Steel Company and the Maryland Steel Company. "A Method of Producing High-Class Steel from Pig-Iron containing Chromium, Nickel and Cobalt," by Arthur Windsor Richards, Iron and Steel Institute, London, May, 1907. "Chromiferous Iron Ores of Greece and their Utilization," by Herbert K. Scott, Iron and Steel Institute, London, 1913.

[2] Paper read at Pittsburgh meeting Iron and Steel Institute, Oct. 25, 1912. Iron Age, Oct. 31, 1912, pp. 1028 to 1031, and Aug. 19, 1915, p. 416.

Hibbard[1] says:—

Steel made in part of Mayari iron is giving good service in rails and particularly in track bolts, which are heat treated to give the metal an elastic limit of 75,000 pounds per square inch.

Why these rails are satisfactory when other chrome-nickel steels were not has not been explained. The chief differences seem to be (1) that these Mayari steel rails have less of the alloying elements because Mayari iron is used only in part in them, and (2) that the steel is made in the open-hearth furnace.

The use of steel containing Mayari iron is increasing, and the demand is enough to induce the production synthetically of steels of the same composition by adding nickel and chromium to simple steels in the Mayari proportions.

He adds:—

It is likely that, in the near future, the tonnage of Mayari steels will surpass that of all the other chrome-nickel steels taken together.

The Mayari Steels

The following has been extracted from a paper by J. A. L. Waddell.[2] After discussing the value of ordinary nickel steels for structural work, he says:—

There is a fact concerning nickel steel known to the profession, but which, as far as the author can learn, had not until a very short time ago been stated in print, viz., that the Pennsylvania Steel Company has obtained control of an iron mine containing a small percentage of nickel; and is, consequently, able to place upon the market a low-grade nickel steel at a reasonable excess cost above that of carbon steel. This steel has been denominated by its makers "Mayari steel." It is a natural alloy of nickel-chromium steel, containing from 1.00 per cent. to 1.50 per cent. of nickel and from 0.20 per cent. to 0.75 per cent. of chromium, with sulphur below 0.04 per cent., phosphorus below 0.03 per cent., and manganese as desired. The carbon range is from 0.03 per cent. to 1.50 per cent., depending upon the the application of the steel. The ore comes from a deposit of some 25,000 acres at Mayari in the Province of Oriente on the Island of Cuba. It is estimated that there are 500,000,000 tons of this ore in sight. Mayari steel is made only by the Pennsylvania Steel Company and the Maryland Steel Company. By a slight modification of the open hearth process, it is produced without the necessity of adding alloying elements in the furnace or ladle. Like other nickel steels, it offers greater resistance to corrosion than do the ordinary carbon steels.

Desiring to obtain for the preparation of this memo. some authentic information concerning the new alloy, the author wrote to the Pennsylvania Steel Company asking certain questions about it, and received in reply a letter from J. V. W. Reynders, Esq., C.E., the Vice-President of the Company, from which the following is an extract:

"Our principal experience on Mayari steel in bridge work has been in connection with the manufacture and fabrication of the large bridge which is to span the Mississippi River at Memphis. So much steel has now been made for this contract that we have accurate information on the properties which we can develop.

"On this bridge alternate quotations on carbon and alloy steel designs were submitted, the specifications for the alloy steel, outside of rivet and eye-bar steel, being as follows:

Tensile strength	85,000 to 100,000 lbs. per sq. in.
Elastic limit, not less than	50,000 " " " "
Elongation in 8 in., not less than	$\frac{1,600,000}{T.S.}$
Reduction of area, not less than	30.0 per cent.

"The manganese in the steel was limited to .80 per cent., silicon to .15 per cent., carbon to .40 per cent, and a minimum of 1.20 per cent. nickel was required, but the individual bidder was allowed to select his own analysis except as it might be limited by these general figures. No limits were given for chromium or vanadium.

"We quoted on the basis of using a steel made from the Mayari ore, which we import from our mines on the north coast of Cuba, and on this basis the contract was awarded us.

"As you doubtless know, this Mayari ore lies just under a thin top soil in a comparatively thin bed of great area. The ore contains naturally a large amount of moisture, a part of which is in the combined form. It has been our practice before shipping this ore to the United States to run it through rotary nodulizing kilns, which agglomerate the fine ore and drive out the moisture. The nodulized product carries about 57 per cent. of iron.

[1] Manufacture and Uses of Alloy Steels, U.S. Bureau of Mines, 1916, p. 50.

[2] Paper 108. Trans. Intern. Eng. Congress, San Francisco, 1915, 41 pages.

"By a selection of the ore, steel can be produced with a uniform nickel content, which may be varied at will between quite wide limits It has been found, however, that a content of approximately 1.40 per cent. is sufficiently high for bridge steel for most purposes. The steel is normally produced with only the usual additions in the open hearth furnace, although occasionally a small amount of chromium is added.

"It has been our experience that this alloy steel works quite as well in the shops as any other steel with which we are familiar, making due allowance, of course, for the increased toughness. We find that it is easier to work than 3¼ per cent nickel steel.

"It is difficult to give an exact extra which we would charge for rolled sections or plates of Mayari steel over the market price of similar sections of carbon steel. We do not expect, however, that it will be necessary at any time to charge an extra of more than one cent per pound. The excess price for manufactured bridges depends on so many circumstances that it is almost impossible to give any figure. It will vary greatly, of course, as the relative proportions of carbon and Mayari steels in the finished bridge are varied

"With regard to quantity, we expect shortly to be in a position to produce from 18 000 to 20,000 tons per month of Mayari steel shapes, if necessary; but, even for the present, it is safe to say that we can meet any reasonable demand."

Judging from Mr. Reynders' approximate quotation for the rolled metal and from previous experience with nickel steel, the author concludes that the finished metalwork is likely to cost as much as one and a half cents per pound in excess of the market price of corresponding carbon steelwork. This is just what he first estimated would be the limiting excess pound price of nickel steel having an elastic limit of 60,000 lbs, when the excess price of the rolled material was one cent per pound.

The large-scale curves from which were prepared the cost diagrams of the paper on "The Possibilities in Bridge Construction by the Use of High Alloy Steels," hereinafter referred to at length, afford a means of determining the economics of Mayari steel for bridges as compared with nickel steels of 55,000 lbs. and 60,000 lbs. elastic limit. From them are found the following:—

500-ft. Simple Truss Spans—The Mayari steel bridges at 1 5 cents per lb. excess over carbon steel are equal in cost to nickel steel bridges for E. L. = 55,000 lbs. at an excess of 1.9 cents per lb., and to nickel steel bridges for E. L. = 60,000 lbs. at an excess of 2.25 cents per lb. With Mayari steel at 1.0 cents per lb. excess over carbon steel, the corresponding figures are, respectively, 1 35 cts. and 1.7 cts

For equal costs of bridges, as compared with carbon steel, Mayari steel could stand an excess pound price of 2.1 cents for the manufactured superstructure.

1,000-ft. Simple Truss Spans.—With Mayari steel at 1.5 cents per lb. excess, the excess for nickel-steel of E. L. = 55,000 lbs. is 2.25 cents per lb. and that for nickel-steel of E. L. = 60,000 lbs. is 3.0 cents per lb. With Mayari steel at 1.0 cents per lb. excess over carbon steel, the corresponding figures are, respectively, 1.7 cents and 2.4 cents per lb.

For equal costs of bridges, as compared with carbon steel, Mayari steel could stand an excess pound price of 3.75 cents for the manufactured superstructure.

Cantilever Bridges with Openings from 1,000 ft. to 2,000 ft.—Mayari steel bridges at 1.5 cents per lb. excess over carbon steel are equal in cost to nickel steel bridges for E. L. = 55,000 lbs. at an excess of 2.3 cents per lb. and to nickel steel bridges for E. L. = 60,000 lbs. at an excess of 3.1 cents per lb. With Mayari steel at an excess of 1 cent per lb., the corresponding excesses for the other steels would be, respectively, 1.7 cents and 2.5 cents per lb.

For equal costs of bridges, as compared with carbon steel, Mayari steel could stand an excess pound price of 1.85 cents.

From the preceding it is evident that Mayari steel has carbon steel beaten for bridge-work under all conditions, but that if it costs when manufactured 1.5 cents per pound more than that metal, it will probably not be as economic as either of the grades of nickel bridge steel which can be produced commercially to-day. If, however, the manufacturers of Mayari steel and of structures made therefrom can bring the price of their finished metal work down to an excess of one cent per pound as compared with carbon steel, their product will have somewhat more than a fighting chance in the competition. Nevertheless it will always have one serious obstacle to contend against, *viz.*, the irregularity of the composition and characteristics of the finished product. This is shown very clearly in Mr. Reynders' letter; for in his shape-steel tests the elastic limit varies from 54,300 to 64,700 pounds per square inch, the ultimate strength from 91,400 to 98,420 pounds per square inch, the nickel content from 1.27 to 1.51 per cent., and the chromium content from 0.36 to 0 46 per cent. In the plate tests the corresponding variations were, respectively, from 55,270 to 64,660 pounds per square inch, from 90,040 to 99,600 pounds per square inch, from 1.36 to 1.57 per cent., and from 0.31 to 0.49 per cent. Considering that the raw material received very little preparation for smelting, the preceding showing is by no means bad, especially since the records given indicate that no special difficulty has been experienced in complying with the specifications. On the other hand, though, the serious disadvantage under which the alloy labors is strikingly made evident by averaging the elastic limits given in the specimen tests; because the

mean of all the figures is 59,655 lbs., while the requirement was only 50,000 lbs. It is possible that experience in the production of the alloy will result in greater regularity and less cost. If such proves to be the case, Mayari steel is likely to supplant entirely the other alloy bridge steels at present obtainable; but it is far from being the ideal alloy for long-span bridge construction. Even if the inherent irregularity be made truly non-injurious to the metal by always keeping its characteristics well above the specified requirements, there will (for many years, at least) exist in the minds of purchasers the latent doubt of the steel's reliability, and the dread that, without warning, the elastic limit and the ultimate strength may drop dangerously below the minima called for in the specifications. For a long time to come, and perhaps always, it will probably be necessary to test Mayari steel much more thoroughly than carbon steel in order to prevent the utilization of any inferior melt or rolling in the manufacture of bridgework.

Nickel-Copper Steels

The effect of the presence of copper on steel is of special interest in connection with the nickel industry, on account of the possibility of making steel direct from the nickel-copper ores of Sudbury, or from the slag obtained in the ordinary blast furnace or reverberatory smelting of such ores.

The existence of copper in steel was formerly regarded as so pernicious as to prohibit the use of iron ores containing more than a trace of that metal, and most official specifications rigidly excluded it from the finished steel.

Although there is good reason to think that such objection was a matter of prejudice, so far as the presence of copper up to say 0.5 per cent. is concerned and, although cupriferous steels are now often passed on account of their good showing under standard tests, much has still to be done to satisfy manufacturers and users of steel that such ores as those of Sudbury, if selected or dressed to give the required percentage or not to exceed the limit imposed for copper by specifications, are capable of yielding a satisfactory product. In the case of nickel-copper steels, the permissible maximum for copper is far in excess of that for ordinary copper steel.

A number of tests on nickel-copper steels in comparison with other steels have been given in the table on pages 359 and 360 (numbers 15 to 18 and 23 to 29), and reference may be made for further information on smelting work and tests on straight copper steels and on nickel-copper steels made in the ordinary way by adding copper or copper and nickel to steel, or by direct smelting of Sudbury ore, to the publications given in the footnote.[1]

The growth of the copper-steel industry is shown by the fact that a single company, the American Sheet and Tin Plate Company, of Pittsburgh, has increased its shipments of copper steel from 5,000 tons in 1911, when they commenced to market it, to 232,336 tons in 1916.[2]

As an indication of the change which is taking place as regards prejudice against the presence of copper, a note in the advance chapter of the U. S. Geological Survey Report on Sulphur, Pyrite and Sulphuric acid in 1913, p. 24, is worth special attention. It speaks of "a tendency to use copper-bearing steels for rails for railway service," and a consequent probable increase in price for the cupriferous

[1] Haanel, Experiments made at Sault Ste. Marie, Ont., in the smelting of Canadian iron ores, Dept. of Mines, Ottawa, 1907. Kalmus, Summary Report of the Mines Branch of the Dept. of Mines, Ottawa, for 1913, p. 17 to 20, and a number of references given in this Chapter, including especially the opinions quoted from the paper by Dr. J. E. Stead at the September meeting of the Iron and Steel Institute of London. Notes bearing on this matter will also be found in the Reports of the Corrosion Committee of the Institute of Metals and others who have dealt with the general question of the corrosion of steel.

[2] Private communication to the Commission from D. M. Buck, January, 1917.

iron oxide resulting from the roasting of cupriferous pyrites for sulphuric acid. The importance of this expression of opinion from so unbiassed a source, and the enormous supplies of such material which are available throughout the world and commonly (after the roasting has been carried out) at places where transport to the smelter is thoroughly practicable, cannot be over-estimated.

It is true that a large proportion of the evidence which exists in favor of steels containing copper, has no direct bearing upon the presence of copper in nickel steel, but the Commissioners are of opinion that the evidence shows not only that the presence of copper is unobjectionable, but that it may be highly advantageous as regards mechanical properties and resistance to corrosion, and that the improvement effected in nickel steel by the presence of copper is similar to that in ordinary steel; also that a proportion up to about one-third of the nickel in an ordinary structural nickel steel, may be replaced by copper without disadvantage.

In Section D of the Appendix will be found reports made by Professor Alfred Stansfield of McGill University to the Commission on the question generally, and on some special runs made on Sudbury nickel-copper ore for Mr. G. M. Colvocoresses, also information given in the form of evidence by Mr. Colvocoresses himself.

Experiments by Prof. G. A. Guess

The work done for the Commission by Prof. George A. Guess of the Department of Metallurgy in the University of Toronto, in the making and testing of steels containing varying percentages of nickel and copper, strongly supports the view that in ordinary nickel steel copper in limited proportion is not injurious.

Professor Guess has made the following report to the Commission, dated 15th February, 1917:—

Regarding the experiments that I have been conducting, with respect to the possible economic advantages of making a copper-nickel steel direct from Sudbury ore, and to the physical character of such steel, much interesting work remains to be done.

A quantity of copper nickel ore from Sudbury was furnished me. This was crushed to 20-mesh and roasted in a small Wedge roasting furnace. The calcines obtained had the following composition:—

SiO_2	Al_2O_3	Fe.	CaO	MgO	S	Cu	Ni
8.5	2.25	55.0	1.4	1.8	1.95	0.78	3.42

The roaster was run on three eight-hour shifts. The men were not familiar with roasting, and no doubt the ore was permitted to get too hot, making it finally impossible to get the sulphur down to the desired point.

Careful roasting of the same material at 20-mesh in a muffle, 3 kilos on 1 square foot of hearth, for 6 hours at 600° C., gave a calcine having a sulphur content of 0.27 per cent.

A quantity of these Wedge-furnace calcines were taken to an electric furnace plant in order to smelt them into steel. The furnaces in the plant were not in sufficient control, and results were very unsatisfactory. The only ingot that was made was found full of blow holes, and absolutely unforgeable.

It was therefore decided to build a small tilting electric furnace in the metallurgical laboratory of the University of Toronto. This has been done, and several heats have been made in it.

It was also thought advisable to produce a series of 3½ per cent. copper-nickel steels, with varying ratios of copper to nickel, in order to study the quality of such steels. These were made in crucibles heated in an electric resistance furnace. The steels were made from boiler iron punchings, pure nickel and pure copper. The steel was cast in a vertical ingot mould, 0.02 per cent. of metallic aluminium being added to the crucible just before pouring. The ingots were all sound, free from blow holes, and with a pipe.

The composition of the steels so far made is shown in Table I. The first eight steels were made as described Nos. 10 and 11 were made in the electric furnace from roasted ore and finished in the crucible.

Table I: Composition of Steels

No.	C.	Si.	Mn.	S.	Ni.	Cu.
1...........	.56	.37	.475	.068	2.3	1.01
2...........	.43	....	....	....	2.1	1.20
3...........	.76	....	....	....	2.0	1.3
4...........	.53	....	....	....	3.43	.03
5...........	.63	.30	....	.06	1.8	1.7
6...........	.53	.21	....	.05	2.45	.84
7...........	.57	.44	....	.055	2.70	.60
8...........	.38	.28	....	.052	2.94	.5
10...........	.76	.24	....	.1	3.00	.72
11...........	.57	.07	.325	.07	2.5	.92

These steels were forged by the John Whitfield Company, Toronto, and Mr. Whitfield found that they all worked very nicely save number 10. He also machined and prepared two test pieces from each steel. These test pieces were threaded on each end.

One of each of these pieces was given the following heat treatment: Heated to 850° C. and quenched in water, re-heated to 400° C., and cooled slowly. This heat treatment developed cracks in many of the steels, so that Table II. shows very few results from this test. Many of the specimens broke in the bottom of the V-shaped thread. Other heat treatments are being made on these steels.

Table II: Tests after Heat Treatment

No.	C. per cent.	Ni. per cent.	Cu. per cent.	Elastic limit lbs. per sq. in.	Tensile Strength lbs. per sq. in	Elongation per cent. in 2 in.	Reduction of area per cent.
2	.43	2.1	1.2	130,800	162,600	4.5	27.5
4	.53	3.43	0.03	102,000	203,400	6.5	30.0
5	.63	1.8	1.7	156,000	*	....	....
6	.53	2.45	.8	126,000	*	....	....
8	.38	2.94	.50	184,400	*	....	....

* Broke in the thread.

The other set of pieces was broken as received from the John Whitfield Company and the results are shown in Table III.

Table III: Tests of Natural Steel

No.	C. per cent.	Ni. per cent.	Cu. per cent.	Elastic limit lbs. per sq. in.	Tensile Strength lbs. per sq. in.	Elongation per cent. in 2 in.	Reduction of area per cent.
1	.56	2.3	1.01	86,000	132,200	11.5	22.7
2	.43	2.1	1.2	82,600	110,400	22.0	48.0
3	.75	2.0	1.3	113,600	149,000	11.1	24.5
4	.53	3.43	0.03	77,400	115,400	20.0	38.3
5	.63	1.8	1.7	98,200	140,800	11.6	17.8
6	.53	2.45	.8	80,000	111,600	19.1	38.3
7	.57	2.70	.64	80,600	126,400	14.0	28.5
8	.38	2.94	.50	70,400	100,600	18.5	32.8
10	.76	3.00	.72	133,200	133,200	1.0	nil
11	.57	2.5	.92	79,600	128,200	12.5	17.0

It is evident from the results shown in Table III that these laboratory-made steels are of good quality.

For comparison purposes in Table IV are shown tests on nickel steels as reported by McWilliam and Barnes in the Journal of the Iron and Steel Institute, Vol. I, 1911, page 277.

Table IV: Comparative Tests on Natural Steel

No.	C.	Ni.	Yield point tons per sq. in.	Tensile strength tons per sq. in.	Elongation per cent in 2 in.	Reduction of area per cent.
1	.47	2.92	25.0	42.6	22.0	44.6
2	.67	2.96	27.0	51.5	19.0	36.7
3	.74	2.98	34.0	57.9	14.0	25.2

Table V shows tests of steel No. 1, carbon .47, Ni 2.92 with different heat treatments.

Table V: Tests with Varying Heat Treatment

Yield point tons per sq. in.	Tensile strength tons per sq. in.	Elongation per cent. in 2 in.	Reduction of area per cent
25.0	42.6	22.0	44.6
24.8	41.5	23.0	45.9
19.2	32.1	28.0	48.7
48.8	66.6	18.0	54.6
42.4	60.4	19.0	53.7
33.6	47.0	26.0	58.2

It is my opinion that an electric furnace is by no means necessary in any stage of the process for the production of copper-nickel steel from Sudbury ores. For small scale work in a laboratory, it is the most convenient source of heat. The iron and steel worker who may be interested in this metallurgy, will know best how calcines from 20-mesh ore may be smelted. He will know the relative advantages of nodulizing or of sintering. For these reasons it would seem best to direct attention to:—

1. The preparation and roasting of sulphide ore.
2. The elimination of the sulphur left in the calcines.
3. The losses of copper and nickel in the slags made.
4. The properties of copper-nickel steels as compared with nickel steels.

In regard to the preparation and roasting of the sulphide ore: the lower the silica in the ore the higher will be the sulphides, the easier it will roast, the less will be the quantity of lime required in the smelting. The ore should be crushed to about 20-mesh before roasting, and will roast with its own heat down to about 8 per cent. sulphur. On the lower hearths, heat will have to be supplied. But it will be possible to roast to 1 per cent. sulphur at a cost not exceeding $1.00 per ton.

The presence of copper and nickel does not appear to make the removal of sulphur by a basic slag difficult. The calcines from which No. 11 steel was made had a sulphur content of .52 per cent. There was made just the one basic slag, and the resulting steel had .07 per cent.

The small amount of copper and nickel that will be lost in the slags is shown in the following analyses of slags which were made in this work.

Slags from smelting of calcines in the tilting laboratory furnace: CaO 30.8, S 3.7, Ni .245, Cu .062. Slag made at electric furnace plant: Fe 1.0, Cu .015, Ni .07.

The following slag was likewise made at the electric furnace plant. It broke out through the furnace before reduction was evidently complete. The assay is from a large mass of the slag.

SiO_2	Fe	CaO	Mgo	Ni[1]	Cu
19.0	26.6	21.0	12.5	.03675	.0707

A 3.5 per cent. nickel steel contains 70 lbs. of nickel per ton of the steel. Commercial nickel is usually quoted at 40 cents per lb. Let us say that the steel companies pay 35 cents per lb. There is then in a ton of 3.5 per cent. nickel steel $24.50 worth of nickel.

In order to produce such a steel without dilution, our calcines containing 55 per cent. iron should have 1.92 per cent. total copper and nickel. It would appear to me that the $24.50 worth of metal in the ton of steel so produced would leave a big margin, after paying for the cost of roasting the ore, and the additional expense of smelting a fine instead

[1] This nickel assay, which looks very low, has been carefully re-checked.

of a coarse ore. This is, however, taking the extreme case. The copper-nickel content of the Sudbury ores is such that they can stand dilution either with coarse iron ores in the smelting operation, or with scrap and ore to the pig produced.

This dilution in a 5 per cent. copper-nickel ore containing 40 per cent. iron, which would be about 50 per cent. iron in the calcines, would be approximately 250 per cent. In other words, one ton of pig so made could be diluted with ordinary iron or steel to produce 3½ tons of product.

The value of this process of producing nickel-copper steel is based on the belief that copper may replace a very considerable amount of the nickel in a 3 5 per cent. nickel steel without producing an inferior article, which belief is, I think, well founded.

Possible Production from Sudbury Ores

It would seem that two methods of obtaining nickel-copper steel from the Sudbury ores are possible: (1) the direct smelting of raw or roasted nickel-copper ore, (2) the treatment of slag from nickel smelting. In this slag, practically the whole of the iron originally present in the ore has become concentrated, and it carries also sufficient nickel and copper to add considerably to the value of the pig iron obtainable from it. The original ore of the Sudbury district and the slag obtained from it may be taken as containing roughly:—

	Ore per cent.	Slag per cent.
Iron	35 to 40	40
Sulphur	25 to 30	1.25 to 1 5
Nickel	3 to 4	0.3 to 0 4
Copper	1 5 to 2	0.25

On a basis of 1,000,000 tons of slag per annum (about two-thirds of the present output) and taking the lowest value in each case, there is a theoretical possibility of recovering per annum, over 400,000 tons of nickel-copper pig iron, containing 400,000 tons of iron, 3,000 tons of nickel and 2,500 tons of copper.

It is not suggested that the treatment of slag for the production of such pig would be highly profitable, but it is likely that it would be an important additional source of revenue, and it is certain that a considerable amount of the nickel and copper at present lost, would be thus recoverable in alloy with iron, so that nickeliferous pig for the production of nickel steel would be produced in competition with such other "natural" nickel steels as have already been referred to in this Chapter as being produced from Cuban ore, which contains chromium, but no copper, and which, on account of the presence of the chromium, is somewhat difficult to smelt, although the product ultimately obtained is a desirable nickel-chrome steel.

The trade prejudice against the presence of copper in ordinary steel and nickel steel, is comparable to that which formerly actually existed against the pure nickel produced by the Mond Nickel Company from Sudbury ore. The users were experienced in the use of New Caledonian nickel, and put down some of its good qualities to the absence of copper, which they apparently considered must be present in Canadian nickel. The Mond nickel contained no copper, but, on account of its purity, was difficult to melt. The Mond Company had trouble, not only with the small and more or less ignorant and prejudiced users, but even with the British Admiralty and other important buyers, and it was only after the greatest difficulty and heavy expenditure that they overcame the prejudice.

A large amount of research work by persons totally uninterested in the nickel trade, and many of them originally opposed to the use of steel containing copper, has been published. It shows that the presence of copper, within certain limits, is not only unobjectionable but probably advantageous, and the addition of copper to steel has been suggested and adopted. It is, therefore, practically certain that, provided cupriferous nickel steel can be made at a small profit from the Ontario ores or slags, there will be no difficulty in the future, in disposing of it.

So convinced are some steelmakers of the suitability of nickel-copper steel for use in place of straight nickel steel that a considerable amount of it has been made by alloying Monel metal (a well-known nickel-copper alloy which has already been described in this Chapter) with steel. It has been found to stand the necessary tests, and it is stated that similar nickel-copper steels are in use in Germany. The possibility of making such a steel without the necessity of starting with pure nickel and pure copper, is a powerful argument in favour of the direct smelting of nickel-copper ores.

At interviews with many experts in England and the United States, the opinion was expressed that there was still room for much research work to settle the uses for which steel containing copper is advantageous, and the physical qualities of alloys of such composition as are likely to be most readily obtained by direct smelting of selected or other Sudbury nickel-copper ores.

Dr. J. E. Stead on Copper in Steel

The opinion that the presence of copper within limits not dreamt of ten years ago, is not injurious for a large variety of purposes including the principal ones, i.e., where strength and resistance to corrosion are desired, appears to be almost universal, and the following statement has been taken from a paper read by Dr. Stead[1] at the September meeting of the Iron and Steel Institute, London, 1916:—

Copper Steels

E. J. Ball[2] and A. Wingham (1889) studied the influence of copper on the tensile strength of cast steel. The alloys were made in crucibles, and test pieces 1 × ¼ × $\frac{11}{16}$ inch were cut from the solid metal and after annealing were submitted to tensile tests, with the following results:

Copper Per Cent.	Carbon Per Cent.	Tensile Strength. Tons Per Square Inch.
....	0.133	29.0
0.647	0.102	18.3
2.124	0.217	36.6
3.630	0.380	47.6
7.171	0.712	56.0
4.10	0.183	43.2
4.44	trace	34.3

The forging tests were satisfactory, with the exception of the specimen containing 7.171 per cent. copper, which forged well in the cold but was redshort.

It was concluded that within certain limits copper did not prejudicially affect the mechanical properties of steel.

[1] J. E Stead, Jour. Iron and Steel Institute, London, September, 1916, pp. 75 to 82.
[2] Journal of the Iron and Steel Institute, 1889, No. I, p. 123.

Professor Arnold [1] published the result of melting iron with 1.81 per cent. copper. The crucible ingot was rolled into bars, and these were tested under the same conditions as bars rolled from an ingot without copper.

The results are given below:

	Iron with 0.03 per cent. Carbon.	Iron with 1.81 per cent. Copper and 0.1 per cent. Carbon.	Difference.
Yield point	14.40 tons	30.8 tons	16.4
Maximum stress	21.8 "	34.8 "	13.0
Elongation in 2 inches	47.00 per cent.	30.5 per cent.	16.5
Reduction in area	76.5 "	62.2 "	13.7

Calculated after allowing for difference in carbon:

	Difference Due to 1.81 per cent. Copper.	Difference Due to 0.10 per cent. Copper.
Increase in yield point	15.3 tons	0.84 tons
" maximum stress	10.3 "	0.56 "
Decrease in elongation	13.6 per cent.	0.75 per cent.
" reduction of area	8.6 "	0.47 "

A. L. Colby's [2] investigations show that small percentages of copper have no injurious effect on the physical properties of steel. A steel shaft 15 inches in diameter by 14 feet long, corresponding in composition with the propeller shafts adopted by the United States Navy Board, but containing also 0.565 per cent. copper, was forged without difficulty. Test specimens were doubled flat in the cold without showing cracks or flaws, and the tensile strength ranged from 64,680 lbs. to 68,010 lbs. per square inch, the contraction of area being 46.32 to 56.44 per cent., and the elongation in 2 inches 28.5 to 34 per cent. The material was well up to Navy requirements. In another series of tests the material, containing 0.553 per cent. of copper, was forged into a gun-tube, and satisfied the requirements of the United States Navy for a 6-inch gun, which demand a tensile strength of not less than 75,000 lbs. per square inch, combined with an elastic limit of not less than 36,000 lbs. per square inch, and an extension of 20 per cent. on 2 inches. Other investigations were directed to merchant bars, rails, and to nickel steel, all containing copper.

The conclusions drawn are that good steel may contain as much as 1 per cent. of copper without suffering, whilst in any case the properties of the metal in the cold are unaffected.

W. Lipin [3] (1900) found that the addition of copper to Swedish charcoal iron increased the relative fluidity, and the fractured surfaces became more coarsely crystalline and brighter as the copper percentage rose.

4.9 per cent. copper increased the tensile strength from 19 to 22 tons per square inch and did not tend to retain the carbon in the combined state.

When steel was alloyed with copper in varying amounts up to 10 per cent., it was found that as the carbon increased, the copper must be reduced and should not exceed 2 per cent. if the carbon was 0.43 per cent. One per cent of copper may be present in tool steel, but as the hardening effect of copper is so energetic the quenching of the heated steel must be done in oil rather than in water

J. E. Stead and J. Evans [4] tested a number of charges of cupro-steel, with a view to determining the influence of copper on steel rails and plates. Four series of Bessemer rail steels were made containing respectively about 0.5, 0.9, 1.3, and 2 per cent. of copper Comparative tensile tests were made on these steels and on normal Bessemer steel rails containing from 0 012 to 0.033 per cent. copper, with the following results:

[1] Journal of the Iron and Steel Institute, 1894, No. I, page 107.

[2] Iron Age, November 30, 1899, pp. 1-7.

[3] Stahl und Eisen, 1900, Vol. XX, pp. 536, 583.

[4] Journal of the Iron and Steel Institute, 1901, No. I, p. 89.

No I.—Copper, 0.50 Per Cent. Average Results.

	Cupreous.	Normal.	Effect of Copper
Breaking weight (tons per sq. in.)	46.55	44.63	+1.92
Elastic limit (tons per sq. in.)	25.00	25.20	−0.20
Elongation in 2 inches (per cent.)	19.30	20 66	−1.36
Contraction of area (per cent)	21.38	27.56	−6.18
No. II.—Copper, 0.889 Per Cent. Average Results.			
Breaking weight (tons per sq. in.)	49.4	48.0	+1.4
Elastic limit (tons per sq. in.)	27.1	24.8	+2 3
Elongation in 2 inches (per cent.)	23.0	21 0	+2 0
Contraction of area (per cent.)	37.0	32.0	+5.0
No. III.—Copper, 1.286 Per Cent. Average Results.			
Breaking weight (tons per sq. in.)	42.2	41.6	+0.6
Elastic limit (tons per sq. in.)	28.0	23.4	+4.6
Elongation in 2 inches (per cent.)	23.0	26 0	−3.0
Contraction of area (per cent.)	35.0	39.5	−4 5
No. IV.—Copper, 2.00 Per Cent. Average Results.			
Breaking weight (tons per sq. in.)	49.7	39.7	+10.0
Elastic limit (tons per sq. in)	35.9	22 1	+13.8
Elongation in 2 inches (per cent.)	21.5	27.0	−6.5
Contraction of area (per cent.)	35.4	41.0	−5.6

Nos. I., II., and III rolled well. No. IV., the cuprous rail, burst in the flanges during rolling, but it was proved that the material had been overheated.

They found that up to 1 per cent. copper there is very little effect, but with from 1 per cent. to 2 per cent. copper the yield point and tenacity is raised and the elongation and reduction of area are reduced. Even 2 per cent. copper did not make steel redshort.

Copper and Manganese Steels

J. O. Arnold[1] (1894) made mechanical tests on steel alloyed with 1.8 per cent. copper, and the following table shows the results compared with those obtained with pure iron alloyed with 1.29 per cent. manganese.

	Pure Iron. Per Cent.	Manganese, 1.29 Per Cent. Per Cent.	Copper, 1.81 Per Cent. Per Cent.
Elastic limit	14.39	22.72	30.8
Tensile strength	21.77	32.16	34.8
Elongation	47.00	35.00	30.5
Reduction of area	76.50	65.00	62.2
Carbon	0.04	0.10	0.10
Manganese	....	1.29	....
Copper	....	....	1.81

The great difference between the effect of manganese and copper appears to be that copper has greater influence than manganese in raising the elastic limit.

[1] Journal of the Iron and Steel Institute, 1894, No. I, p. 107.

Copper-Nickel Steels

G. H. Clamer[1] (1910) has examined the properties of iron-nickel and iron-copper alloys. Alloys containing 5 to 20 per cent. copper are hard, brittle, and redshort, but on addition of 20 to 50 per cent. nickel they become tough, malleable, and ductile. He has produced an alloy consisting of iron, 65 per cent.; nickel, 25 per cent.; copper, 10 per cent.; and carbon, 0.2 per cent., having tensile strength of 96,100 lbs. per square inch; elastic limit, 51,750 lbs. per square inch; an elongation in 2 inches of 42 per cent., and a reduction in area of 53.7 per cent.

J. A. Mathews,[2] in discussing Clamer's experiments, gives an account of his own investigations on nickel-copper steels. The analysis of the material was as follows:

	Per Cent.
Carbon	0 44
Silicon	0.034
Manganese	0.50
Phosphorus	0.013
Sulphur	0 013
Nickel	3.62
Copper	0.48

All the nickel and copper present were contained in the original pig iron. For the sake of comparing this steel with another of approximately the same analysis but free from copper, an open-hearth nickel steel was selected of the following composition:

	Per Cent.
Carbon	0.46
Silicon	0 066
Manganese	0 70
Phosphorus	0.021
Sulphur	0.034
Nickel	3 36

On testing for copper, it was found that this material also contained about 0.1 per cent. of copper. The physical tests were made in duplicate on round bars ⅞ inch diameter, and the bars from the two heats were annealed at the same time, so as to avoid any possible difference in the annealing temperature. The open-hearth steel machined somewhat more freely than the copper-nickel steel, but here the superiority ended.

The tensile tests of the rolled material showed:

	Open-hearth Nickel-Steel.	Copper-nickel Steel.
Elastic limit	74,626 lbs.	72,400 lbs.
Ultimate strength	122,000 "	115,000 "
Elongation in 2 inches	16 per cent.	22 per cent.
Reduction of area	34 "	51 "

In the annealed condition, the results were:

	Open-hearth Nickel-Steel.	Copper-nickel Steel.
Elastic limit	64,750 lbs.	63,750 lbs.
Ultimate strength	119,000 "	107,300 "
Elongation in 2 inches	17 per cent.	25 per cent.
Reduction of area	37.5 "	48 "

In all the tests, the great superiority of the copper-nickel steel in elongation and reduction of area is most noticeable. There is, further, absolutely no evidence to show that the copper has exerted a harmful influence upon the nickel steel, and the superiority of the one material must either be ascribed to the presence of copper or to the electric method of melting or to both acting jointly.

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[1] Proceedings of the American Society for Testing Materials, 1910, Vol. 10, p. 267.
[2] Ibid., pp. 274-279.

Summary and Comments.

Copper for more than two generations has had a very bad name, owing to the mistaken observation of certain investigators whose names need not be referred to

Even to-day, one comes across steel specifications in which copper is barred, which can only be regarded as an indication of the ignorance, if not stupidity, of those who prescribe the composition of steels, for it has been long ago proved that copper in steel, instead of being an evil, is quite harmless and is sometimes distinctly beneficial.

The evidence is overwhelming that small quantities of copper, say about 0.5 per cent., have little or no material influence on the mechanical properties. It is still held by some that copper tends to make steel redshort. Many authorities who have made reliable trials have found that it has no bad effect.

Arnold, Stead, and Evans found the effect of 0.1 per cent. copper to be:—

	Soft Steel.	Medium Carbon Steel.
To increase the yield point	0.84 tons	0 32 tons
To increase the maximum stress	0.56 "	0.26 "
To decrease elongation	0.75 per cent.	0.25 per cent.
To decrease reduction of area	0.47 "	0.50 "

It is certain from these figures that the effect of small percentages of copper is slight, but that what effect it has is in its favour. It raises the yield point and tensile strength and has little effect on the ductility.

Some of the finest tool steel ever made contained 0.2 per cent. copper.

It has been proved by Dr. Stead and others that even small quantities of copper in steel makes it more resistant to acid corrosion, and D. M. Buck, in a paper read before the American Iron and Steel Institute, May 28, 1915, presented much evidence to show that copper in sheets preserves them from general corrosion.

Surely it is time that prejudice against copper should be abandoned. Pernicious prejudice has prevented the importation into Britain of cupreous iron ores which are really excellent for steel-making.

Such a definite expression of opinion from Dr. Stead, one of the best known English experts in the metallurgy of steel, is of the utmost importance. It is the most recent pronouncement on the question; it is based on long experience, and it will undoubtedly assist in the increase in the use of steels containing copper, whether deliberately added, or present on account of its existence in the original ore.

Effect of Copper in Assisting Resistance to Corrosion

A paper read before the New York meeting of the American Electrochemical Society, September, 1916, by E. A. and L. T. Richardson, entitled "Observations upon the Atmospheric Corrosion of Commercial Sheet Iron—Particularly in Regard to the Influence of Copper and Mill Scale," contains a useful résumé of the present position, although it deals mainly with alloys in which nickel is not an essential constituent.

The question of superiority between copper-bearing steel and pure iron as regards rust-resisting properties is discussed. The work done on the subject up to 1910, having indicated that copper in steel is a benefit as regards resistance to corrosion, copper-bearing steel was placed on the market, and the controversy became acute. The authors state that the tests generally made are of doubtful value to the ultimate consumer, as the materials tested are usually made specially for tests, and are not those actually purchasable on the open market.

They deal with steel, puddled iron, commercially pure iron and copper-bearing steel. The different materials obtained were in the form of black sheets of 26 gauge, as follows:—

1. Bessemer Steel.
2. Open Hearth Steel.
3. Charcoal Iron.
4. Commercially Pure Iron.
5. Commercially Pure Iron.
6. Copper-bearing Iron.
7. Copper-bearing Steel.
8. Copper-bearing Bessemer Steel.
9. Copper-bearing Open Hearth Steel.

A complete analysis is given of each sample.

In each case, a set was tested as bought, and after removal of scale by pickling in sulphuric acid, thoroughly washing with water and drying, the surface was finally cleaned with fine emery cloth. The point of failure was taken to be when the metal could be seen to be perforated when the rust was removed by gentle tapping with a blunt object such as a file or nail.

When the samples were exposed to the weather (May 24, 1914) a difference was very soon noted in the character of the rust on the different materials, the Bessemer and open hearth steel samples showing a yellowish-red rust which loosened rapidly, and the others a dark red rust, very adherent, especially in the case of the copper-steels. Photographs are given of three different characteristic samples about a year after the test was started.

The results of the tests are given in a short table, showing a decided superiority for the copper-bearing steels, which, at the time the article was written, were still intact. The pure irons (including charcoal iron) were superior to steel. The addition of copper to steel in amounts up to about 0.25 per cent. is stated to cause a remarkable increase in its ability to resist atmospheric corrosion (in the case of the Bessemer or open-hearth steel, an increased resistance of 300 to 400 per cent.). Copper added to pure iron has a similar effect, but to a much less degree. The reason of these differences is not known, but it is supposed to be some beneficial combined effect of the two elements copper and manganese.

A table is given of tests made by D. M. Buck[1] on different materials, and tests referred to at Scottdale, Pa., and in McKeesport city water. The conclusions come to are that the resistance of pure iron to corrosion could be increased by the addition of manganese and copper together, and that additions of manganese to pure iron or steel, even up to 3 or 4 per cent., or more, with a corresponding increase in copper to produce a maximum effect, should give a material more resistant to atmospheric corrosion than the copper steel now on the market.

A summary to the article, contains the following conclusions:—(1) Copper-bearing steels are decidedly superior to pure iron, steel, or charcoal iron. (2) The addition of copper to pure iron increases its resistance to corrosion, but to no such an extent as similar additions to steel. (3) Copper is believed to decrease corrosion through some mutual influence of manganese and copper. (4) The additions of larger amounts of manganese and copper to pure iron or steel are suggested, as well as additions of copper-chromium, copper-vanadium, copper-tungsten, or copper-molybdenum.

[1] Buck, D. M. Recent Progress in Corrosion Resistance, Amer. Iron and Steel Inst., May, 1915. See also D. M. Buck and J. O. Handy, J. of Ind. and Eng. Chem., March, 1916.

CHAPTER VIII

Smelting Nickel Ores

Introduction

Although small quantities of ferro-nickel are prepared by the direct smelting of New Caledonian and other oxidized ores, and many processes have been proposed for the wet treatment of such ores and of sulphide ores, practically the whole of the nickel ore smelted throughout the world is reduced direct in blast or reverberatory furnaces to a low grade, highly ferruginous matte. This is afterwards "converted" or bessemerized to remove practically the whole of the iron, and as much of the sulphur as can be eliminated without excessive loss of nickel, so that a material as rich as possible in nickel, or nickel and copper when both are present, is produced for refining.

This procedure is adopted as being at present the cheapest and most efficient method of concentration for nickel ores, and the methods and plant in use by the several companies in Canada, Norway and New Caledonia, are briefly described in this Chapter. The bessemerized matte ultimately obtained and handed over to the refiner, usually contains about 80 per cent. of nickel plus copper, about 20 per cent. of sulphur, about one-half of one per cent. of iron and as much of the gold, silver, platinum, palladium and other metals of the platinum group as can be recovered by smelting.

The smelting and bessemerizing operations are remarkably similar to those used in copper smelting, but true pyritic smelting has not yet been adopted, nor can bessemerizing be carried beyond the above proportions without undue loss.

As nickel matte can be readily roasted down to a mere trace of sulphur, the apparently illogical process almost universally adopted, of smelting oxidized nickel ores (which are usually free from sulphur) with sulphur-containing materials, is probably fully justified where such materials are obtainable. It was first adopted in Wales, where all classes of sulphur ores and residues are available, and the alkali waste from sulphuric acid manufacture was ultimately used in preference to any other material for smelting the nickel ore received from New Caledonia. Although the latter country still ships much raw ore, it now smelts down large quantities to a crude matte containing 40 to 50 per cent. nickel (generally 43 to 45 per cent.), 25 to 30 per cent. iron, and 16 to 20 per cent. sulphur. This is commonly shipped to Europe (Havre in France, Kirkintilloch in Scotland, and—prior to the war—Antwerp in Belgium, and Iserlohn in Westphalia), where it is bessemerized so that the final matte contains 75 to 80 per cent. of nickel, 20 to 22 per cent. of sulphur, and about a quarter to a half of one per cent. of iron. Except for the absence of copper, it is of similar composition to the Canadian matte.

Since the war, the crude New Caledonian matte which formerly went to Antwerp and Iserlohn, has been to a large extent sent to the United States Nickel Company at New Brunswick, New Jersey. This company had previously only refined the matte after it had been bessemerized at Antwerp.

The somewhat lower proportion of metal in the bessemerized matte from New Caledonian ore, is due to the heavier loss of nickel which occurs in bessemerizing matte containing no copper. Bessemerizing is therefore commonly stopped before the matte reaches 80 per cent. nickel. On the other hand, the Canadian Copper Company usually bessemerizes to over 80 per cent. of nickel plus copper. Similarly, the matte of the Mond Nickel Company, whose ore is richer in copper than that of any other of the large operating companies, is occasionally enriched much beyond that standard, and is usually one or two per cent. above. A recent exceptional blow yielded a matte containing 41.1 per cent. nickel and 45.4 per cent. copper, or a total of 86.5 per cent. nickel plus copper.

In describing the metallurgy of the nickel industry, it is most convenient to consider (1) the dressing of the ore, (2) its smelting to crude and, finally, bessemerized matte, (3) the nature of the matte, and (4) the refining of the matte.

Considerations in Making Matte

The bessemerized matte forms so distinct a line of demarcation between the smelting and refining, that its production and treatment may almost be regarded as independent industries, just as the smelting of copper ore is usually in the hands of those who operate the mines, whereas the refining of the blister copper produced at the mine is more commonly conducted far away from the smelters, and by individuals or firms who have nothing whatever to do with either mining or smelting. In this respect, the nickel industry, again, has a strong resemblance to the copper industry, although it is impossible to carry the bessemerizing to the production of an alloy of nickel and copper, even at the cost of excessive permanent or temporary losses of nickel. This is mainly due to the fact that nickel oxide does not react with nickel sulphide as copper oxide does with copper sulphide, so that bessemerizing after the iron has been removed, practically means a loss of nickel rather than a removal of sulphur. The great affinity of nickel for sulphur also limits the range for bessemerizing, by causing the charge to freeze while there is still a large proportion of sulphur left. The bessemerizing of nickel matte may, in fact, be said to cease being a profitable operation as soon as the iron has been slagged off. Further particulars as to the nature, etc., of the matte will be found in the Chapter on Refining, under Nickel Matte.

It is important to note that, in making the 80 per cent. matte at present aimed at, the loss, although temporarily heavy, is actually quite small. It appears to be almost entirely due to small particles of matte suspended in the slag, and the practice followed by both the Mond Nickel Company and the Canadian Copper Company is to run the slag from the converters into the large settlers where the ordinary blast furnace or reverberatory slags are collected. The enormous bulk of slag contained in the settlers, its high temperature, and the long time during which it remains liquid, insure the very complete settlement of these small particles of matte and, notwithstanding that the former practice of re-smelting the bessemer slag in the blast furnaces has been abandoned, and time and expense thus saved, the losses in the total mixed slags are actually less than they were before the present system of settling was adopted.

The necessity for adding sulphur in the case of the oxidized ores, has already been referred to, but the ores of Sudbury and most other sulphide ores contain a proportion of sulphur largely in excess of that required for the production of a matte. It is, in fact, usually sufficient for ordinary semi-pyritic smelting, but a large number of attempts at pyritic smelting in Sudbury have been unsuccessful, and the practice is not in use at present, except in Norway, and to a limited extent, by the Mond company. There is, however, reason to hope that pyritic smelting will some day be largely adopted, and that the present wasteful and objectionable heap roasting will thus be avoided.

In blast furnace or reverberatory practice for smelting sulphide ores (unless pyritic smelting is practised), a sufficient quantity of the sulphur must be expelled, either on the roast heaps or in roasting furnaces prior to smelting, or during the smelting operation itself, to insure that the sulphides will not merely be melted out of the ore, but that only sufficient sulphur will be left to form the smallest quantity of matte which will collect the metals wanted, without more than the normal loss in the slag. In the case of both blast and reverberatory practice on the Sudbury nickel-copper ores, it may be taken as a general rule, that a crude ferruginous matte containing 25 per cent. of nickel plus copper can be obtained with a slag loss of about 0.5 per cent. of the two metals, i.e., one-fiftieth of the matte value, and that the losses rise almost in direct proportion to the richness of the matte. The more iron the matte contains, the less loss of nickel and copper will there be in the slag, so that it is better, from the conservation point of view, to keep within the above limit for nickel and copper in the first matte with most of the Sudbury ores, rather than to adopt the more tempting procedure of obtaining a higher grade matte, and a correspondingly greater output from the furnace.

It is interesting to note that, although all the companies aim at a final bessemerized matte containing about 80 per cent. of the mixed metals, their procedure is very different, partly on account of differences in the relative proportions of nickel and copper, or in the mineralogical nature of the ore treated, and partly through the natural differences in opinion among metallurgists. The final results are remarkably similar both as to value and tenor of products, losses and costs, so that the differences in methods are especially important to those who have views as to possible improvement in any of the standard operations.

It may be stated generally that the Canadian Copper Company and the Mond Nickel Company have spared neither trouble nor expense in experimenting, in modifying their plant and methods when found advisable, and even in scrapping valuable plant when justifiable improvements have been discovered. Each company has the most efficient plant which could be designed, and although each is constantly making improvements, these are alterations in details rather than radical changes in procedure. As a whole, the improvements during the last ten years have been very great and, even since the Commission commenced its work, many changes which will have a marked effect on the industry, have been made.

Dressing the Ore

Although hand-picking from belts, etc., is largely carried out by both companies, the richness of the ores at present being worked in Ontario renders careful

picking or any system of wet dressing on tables, etc., less important than it may become in the future. Much experimental work has been done by the two companies and by others, and there is no doubt that, ere long, they or others will be employing dressing processes, including oil-flotation, as is common with other pyritic ores.

Magnetic separation has not proved successful or promising, either for crude concentration, or for separation of the magnetic nickeliferous pyrrhotite from the purely copper- or iron-bearing minerals, but although there is little object in any incomplete method of separation under present methods of matte refining, it would be highly desirable to be able to obtain even a portion of the nickel as a sulphide mixed with a minimum of copper sulphide, if there is any intention of smelting it direct for the production of nickel-copper steel (see Chapter VII dealing with Nickel Steel). In this connection, it may be pointed out that many methods of selective flotation are now in operation which secure a profitable separation from such mixtures as zinc blende and galena, chalcopyrite and ordinary pyrite, etc., all of which have been described in the technical press, and the most important of which have been collected in T. J. Hoover's book on Oil Flotation. A process invented by Professor H. E. T. Haultain[1] of the University of Toronto, is stated to have yielded on the Sudbury ore, a concentrate containing copper with little nickel, another containing nickel with very little copper, and a middling product containing the two metals in about the proportion in which they occur in the original ore.

As regards lump and fine ore, the Canadian Copper Company considers all which passes through the one-inch trommel holes at the crushing plant as "fines." This amounted in 1915 and 1916, to 30 per cent. of the whole ore mined. The only selection of "rock" from ore is on the picking belts. The rock thus discarded amounts to about 19 per cent. of the material hoisted, and carries about 0.62 per cent. nickel and 0.60 per cent. copper, as compared with the ore which carries 3.58 per cent. nickel and 1.58 per cent. copper.

In 1915, 21 per cent. of the ore smelted by the Mond Nickel Company was fines, and 79 per cent. lump.

In connection with the dressing of the Sudbury ores, the following extract from a memorandum from the Mond Nickel Company to the Commission, dated 27th September, 1915, is of importance:

> Returning to the discussion of grade of ores, we may state that, with smelting ores generally, as the grade diminishes, a point is quickly reached at which these ores must receive a previous treatment by some form of concentration, before smelting. This necessitates a careful separation of the grades of ore by hand-sorting into classes, one of which, the richer or higher in grade, is treated directly in smelting furnaces (being therefore usually known as "direct smelting ore") and the other of which, the poorer in metal contents or lower in grade, is concentrated before smelting (being therefore usually termed "concentrating ore").
>
> The Mond Nickel Company is at present spending a large sum of money in working out the best technical method of concentration for Sudbury ores By these experiments it will ascertain the economic limits of grades of ore for direct smelting and concentrating. These new limits must be obtained for unmined ores, so as to ascertain especially the lowest grade of ore that can be profitably mined in view of the improved treatment. The same limits must also be ascertained for ores already mined, in order to determine the economic limits for the two classes of ores, and especially the lowest grade of ore that can be profitably worked by the improved treatment, after the cost of mining is paid.

[1] Canadian Mining Journal, August 15, 1916, p. 387.

When ascertained, these new limits will become serious operating factors at the mines and at the reduction works. This means that large tonnages of material heretofore not within the economic limit of mining will become ore and will be mined and treated; it means also that large tonnages of material heretofore mined and sorted out as waste, will likewise come by the improved treatment, within the economic working limit.

Hitherto, concentration of these ores in the Sudbury district has been considered impracticable. But, with improved methods and with larger scale operations and greater economies in treatment in other directions, we are just crossing the threshold of a new era in handling the lower grade ores hitherto not considered profitable to mine and reduce.

Roasting

In Norway, roast heap practice has been entirely abandoned, and smelting is no longer carried out during the summer months on account of the proximity of forests, and of the heavy damages which had to be paid when the smelting was conducted during the summer. Not long ago the Canadian Copper Company transferred its roast heaps to its new yard, in the township of Graham, where the lands are rough, and are included in a tract of similar character which in October, 1915, the Ontario government closed to further settlement. This company has about 250,000 tons of ore roasting on its heaps at one time, and roasts over 60 per cent. of its ore in this way down to a sulphur content of 10 to 12 per cent. On the other hand, the Mond Nickel Company roasts only about 30 per cent. of its ore, and is now doing so only during the winter months. Its roasted product ranges from 7 to 10 per cent. sulphur. The British America Nickel Corporation will not employ heap roasting, and there is reason to hope that the Mond Nickel Company will soon abandon it, and that before many years, it will be a thing of the past in Ontario. The flow-sheet of the Mond Nickel Company, given on page 448, has, in fact, been drawn up to show the whole dressing and smelting treatment without heap roasting. Mr. C. V. Corless, the manager at Coniston, states in a letter dated February 21, 1917:

> We have been running a month or two, experimentally, with no roasted ore whatever in the charge, using only the proper proportion of sinter that the normal ratio of fines would make should we abandon heap-roasting altogether. We intend running for some months in this way while collecting full data for the final calculation as to the economy of the practice. While we are succeeding technically, the calculation as to the economy is much more complicated than would appear at first sight, so that, at present, I can offer no opinion on the economy of this practice. As winter roasting eliminates all damage to neighbours from the roast yard, the question as to abandoning heap roasting altogether will be purely one of economy. My present feeling is that heap-roasting will be eliminated from our operations entirely within a year or two.

The general procedure regarding heap roasting is described in the portion of this Chapter dealing with the Canadian Copper Company's practice. The total roast heap losses are unknown, but the losses due to leaching of the roast heaps by water appear to be between one and two per cent. of the nickel plus copper, and are heavier in nickel than in copper, even in the case of such ores as are richer in the latter metal. This is what might be expected, as the roasting in heaps, resulting in a reduction in the percentage of sulphur from about 25 or 30 per cent. to about 7 to 12 per cent., really produces sub-sulphides of nickel and copper, which would tend to precipitate copper from copper sulphate leached out by the water, and to the dissolving out of nickel from such sub-sulphide to replace the copper.

Only a comparatively small proportion of the fines produced at the mine can be roasted in the heaps, as too large a quantity mixed with or covering the coarse

ore would prevent efficient roasting, and the bulk of the fines, which probably average about one-third of the total ore mined, goes to the smelters, where part is smelted direct, but most is roasted in Wedge furnaces in the case of the Canadian Copper Company, or in Dwight-Lloyd sintering furnaces in the case of the Mond Nickel Company.

Smelting

The general principles of nickel smelting have been already briefly dealt with, and the methods of smelting adopted by the different companies are fully treated later in this chapter under each, but it may be mentioned here that the Canadian Copper Company employs both blast and reverberatory furnaces, whereas the Mond Nickel Company have no reverberatories.

It is convenient, in considering costs, recoveries and profits, to regard the refining as starting with the matte, so that it is based on the analysis of the matte, which is a very definite and well-known figure, instead of upon the analysis of the original ore, which, on account of the variety of the ores mixed for smelting, and the manner in which they are handled and mixed on the roast heaps, etc., is always a matter of doubt from moment to moment, although it is pretty accurately known for the yearly periods over which the accounts are calculated.

The losses in smelting up to the production of an 80 per cent. matte, may be divided into (1) mechanical losses in mining, dressing and transport, (2) losses in the roast heaps, (3) losses in the blast or reverberatory furnace, (4) losses in bessemerizing. The two latter include the temporary losses in the furnaces and in the form of flue dust, and the permanent losses in the slag and in unrecovered flue dust. These losses are naturally heavy, both for nickel and copper, but they do not compare unfavourably with those in ordinary copper smelting.

The methods in use by the Canadian Copper Company and the Mond Nickel Company are thoroughly up-to-date, and do not appear to be capable of any radical improvement. On the other hand, the figures which have been supplied to the Commission by both Companies, some of which are included in the description of their operations, show a regular decrease in the losses, and excepting for the increase due to higher wages and cost of supplies, a decrease in costs throughout. The smelting charges are somewhat difficult to calculate or compare. They may be worked out per ton of ore mined, per ton of ore smelted, per ton of matte produced, or per ton or pound of nickel or copper or mixed metals produced. Any method is deceptive, especially for purposes of comparison, because according to the amount of nickel and copper in the original ore, the number of tons of ore smelted for the production of one ton of matte will vary, whereas the cost per ton of ore varies but slightly. In other words, to smelt low grade ore is much more expensive in comparison with the output of matte than to smelt high grade ore. The Canadian Copper Company, for instance, smelts 17 or 18 tons of ore to produce one ton of matte, the Mond Nickel Company about 20 tons of ore, the Nikkelraffineringsverk at Kristianssands in Norway, about 40 tons, and the British America Nickel Corporation will probably smelt not less than 25 tons of ore per ton of matte produced, and the values of the mattes are greatly different in the four cases. Similarly, 19 or 20 tons of 5 per cent. New Caledonian ore would be smelted to produce one ton

of 75 per cent. matte if an 80 per cent. recovery of the nickel is effected. Each ton of matte would, however, be much more valuable than that obtained from a nickel-copper ore.

Converting

As already stated, the low grade matte obtained from the blast or reverberatory furnaces, is enriched to about 80 per cent. of nickel plus copper by a bessemerizing process practically identical with that used in copper smelting, although the conversion cannot be carried profitably much beyond 80 per cent. in the case of nickel-copper sulphides, as compared with nearly 100 per cent. in the case of ordinary copper sulphide. The use of the large rotary converters appears to have been introduced into Canada by the Mond Nickel Company, and the basic lining in place of the acid lining, by the Canadian Copper Company, although bessemerizing in basic-lined furnaces was in use in England on a small scale—commensurate with the amount of matte to be handled—before the advent of Sudbury into the nickel field.

The converters now in use in the Sudbury district are of the most modern and efficient type. They are described and illustrated under the heading Canadian Copper Company, as the kind used by that company is practically identical with that in use by the Mond Nickel Company.

The Canadian Copper Company

Heap Roasting

For heap roasting, a fairly level area of ground, which can be provided with suitable drainage, is necessary. As an illustration of the general arrangement, a description of the Canadian Copper Company's new roast yard in Graham township, opened in February, 1916, may be useful. The yard is reached by a spur from the Algoma Eastern railway at mile 17, is 7,500 feet long, and contains four parallel railroad tracks. At one side is the main running track; of the three service tracks, two are for green ore and run along the outside of the piles, 170 feet apart; the roast ore track runs between the piles equidistant from the two former. This space provides for 350,000 tons of ore, or more if the height of the piles is increased. A single pile contains about 2,500 tons of ore, and is approximately 60 by 100 feet, and 8 feet high. In building a pile, the first operation consists in laying a foundation of wood, usually dead pine, to a depth of a foot or eighteen inches, the surface being roughly levelled. At intervals of about 10 feet, are left flues which are filled with small wood, in order that the fire may penetrate rapidly to the interior of the heap, and produce a more uniform combustion. Coarse ore, amounting to about two-thirds of the whole, is then piled on the wood; followed by a layer of medium sized ore, and lastly by fines which cover the entire heap and regulate the speed of combustion. About 250,000 tons of ore is kept going in the roast yard, i.e., about 100 heaps.

After lighting, the wood burns out in about 60 hours, leaving the ore in vigorous combustion; the pile will continue to burn for three or four months with occasional regulation of the draft to prevent the development of too great a heat

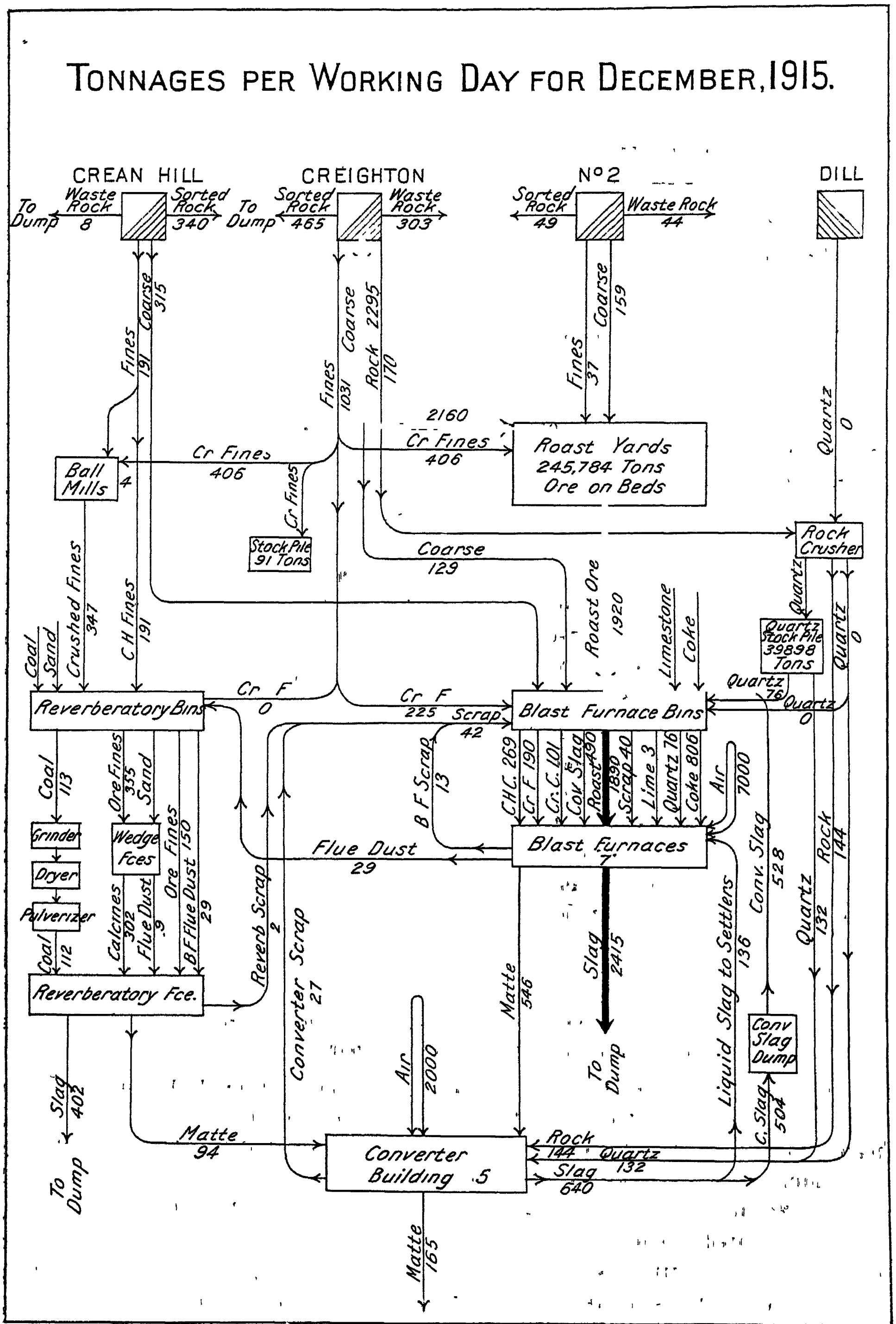


Fig. 67—Flow-sheet, Canadian Copper Company, Copper Cliff, Ontario.

and consequent fusion of the ore. The following table shows the roast yard costs during the last three years:—

Roast Yard Costs, Canadian Copper Company.

Cost per ton for	1914	1915	1916	3 Years
Transferring	$ .149	$ .139	$ .152	$ .147
Roasting	.268	.281	.272	.274
Transp n C.C.	.079	.074	.075	.076
Roast Ore	2.922	2.568	2.582	2.675

During the roasting, the outer portions of the piles become reddish in colour, due to the oxidation of the iron; and a little sulphur frequently sublimes on the surface during the earlier stages, but is later driven off. The raw ore averages 23 per cent. sulphur, and, after three months' roast, this is reduced to 10 or 12 per cent. The surfaces of the lumps of ore are well oxidized, but the interior is frequently unchanged, the efficiency of the roasting being low as compared with that of a good shelf furnace. A certain amount of sintering or fusion always takes place, and portions of the heaps have frequently to be blasted down. When the roasting is complete, the ore is dug out by steam shovel, and transported in cars to the bins behind the blast furnaces.

Since there is no protection from the weather during roasting, and since soluble sulphites and sulphates of copper, nickel and iron are formed in small quantities during the operation, it is obvious that a portion of the valuable metals is leached out by rain and snow water. There is no accurate knowledge as to the proportion of the metals thus lost, which is, however, believed to be small, probably between 1½ and 2 per cent. of the quantity originally present. Experiments made by the Commission indicate that the losses of nickel are higher than those of copper.

Mechanical Roasting

In addition to the ore which is treated in the roast yard, a quantity of fines is roasted in Wedge furnaces, of which there are four, 22 ft. 6 in. in diameter.

The ore, if oversize, is ground in ball mills to pass 10 mesh, but about 75 per cent. of the product is finer than 20 mesh. Each calciner has 7 hearths, which are heated up at first with oil and afterwards kept up to temperature with coal, although the combustion of the ore furnishes practically all the heat required. About 60 tons per 24 hours is the ordinary output of each furnace, but 100 tons could be reached if desired. The ore, containing about 21 per cent. sulphur, is roasted down to 7 per cent. or a little less, and is then added to the charge for the reverberatory furnace. In 24 hours, there is collected from each furnace, 1½ tons of flue dust, containing about 1½ per cent. of the copper nickel content of the ore roasted during that period.

The design, construction and general working of the Wedge and other mechanical furnaces are fully described in the technical press, including the works of Wilson[1] dealing with the copper smelting and sulphur industries of Canada.

Blast Furnaces

The smelting plant, which is of the most modern design, has been described in considerable detail by G. E. Silvester[2]; additional notes have been furnished through the kindness of D. H. Browne.

The storage bins are of massive timber construction, 700 feet long, 30 feet wide and 32 feet high. Two upper standard gauge tracks, serve for the delivery of raw materials, while two narrow gauge tracks below the bins, and on the same level as the furnace charging floor, convey the desired quantities to the furnaces. The haulage in the latter case is by electric locomotive with a train of eight or nine side-dump cars, each of 3,000 lbs. capacity.

In the furnace building, there are seven blast furnaces of the rectangular type. Five of these are 50 by 204 inches inside at the tuyeres, 19 feet high from the hearth plate to the charging level. Each is rated at 500 tons charge per day; the other two have cross-sections of 48 by 255 inches, and 50 by 306 inches, respectively. There are two tiers of water jackets, the lower or tuyere jackets 8 feet, and the upper 6 feet 4 inches high. Cast iron slabs, provided with water circulation channels and stiffening flanges, have been used as tuyere jackets for some time past, in place of the ordinary steel plate type.

The following details of one of the furnaces have been furnished by the company:—

Width at throat, below apron plates	70 in.
Length " " " "	255¾ in.
Area " " " "	124 sq. ft.
Width above charge doors	94 in.
Length " " "	279 in.
Height, charge floor to centre of downtake	27 ft.
Area of downtake	50.26 sq. ft.
Length at tuyeres	255 in.
Width "	48 in.
Area "	85 sq. ft.
Depth of crucible, centre of tuyere to sole plate	45¾ in.
Centre of tuyere to throat-charge floor	10 ft. 9 in.
" " charge plates	14 ft. 10¼ in.
Total length of water jackets	14 ft. 10½ in.
Bosh-batter of water jackets	17⅞ in.
" " " in. per ft.	2.102
Tuyeres—number of	40
" —area of each	28.27 sq. in.
" —total area—sq. in. per ft. length of furnace	53.2

In the smaller furnaces the blast is introduced through 32 tuyeres at a pressure of 22 to 35 oz.; about 24,000 cubic feet of air is blown in per minute. Each furnace smelts about 300 tons of ore, or 440 tons of charge in 24 hours.

The dust chamber, of the balloon type, is 20 feet in diameter and 500 feet long, lined only for about 12 feet square opposite each downtake; hoppers and clean-out doors every 6 feet discharge directly into cars below.

[1] "Pyrites in Canada: Its Occurrence, Exploitation, Dressing and Uses," and "The Copper Smelting Industries of Canada," by A. W. G. Wilson.

[2] Journ. Can. Min. Inst., Vol. XII, 1909, pp. 218-239.

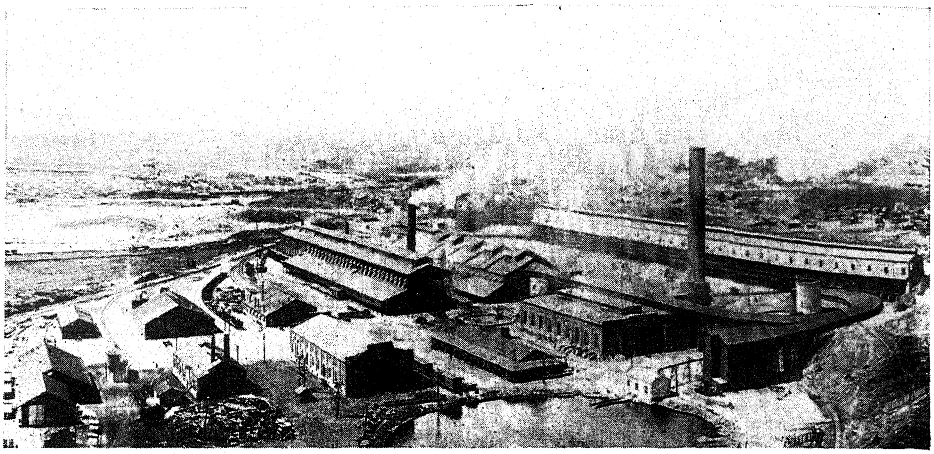


Fig. 68—General View of Copper Cliff Smelting Plant.

Fig. 69—General View of Blast Furnace and Converter Departments, Copper Cliff.

From the furnaces, the molten products flow continuously into oval settlers lined with chrome brick. The matte, with a specific gravity of 4.6 to 4.8, settles to the bottom, while the slag, whose specific gravity is about 3.7, overflows continuously through the slag spout into 25-ton pots, which are hauled to the dump. The matte is tapped off at intervals into 7-ton ladles, which are transferred by rail to the converter building.

The Operation of the Blast Furnaces

Owing to the large proportion of iron and the admixture of rock with the sulphides, the ores from the different mines operated by the company can be blended

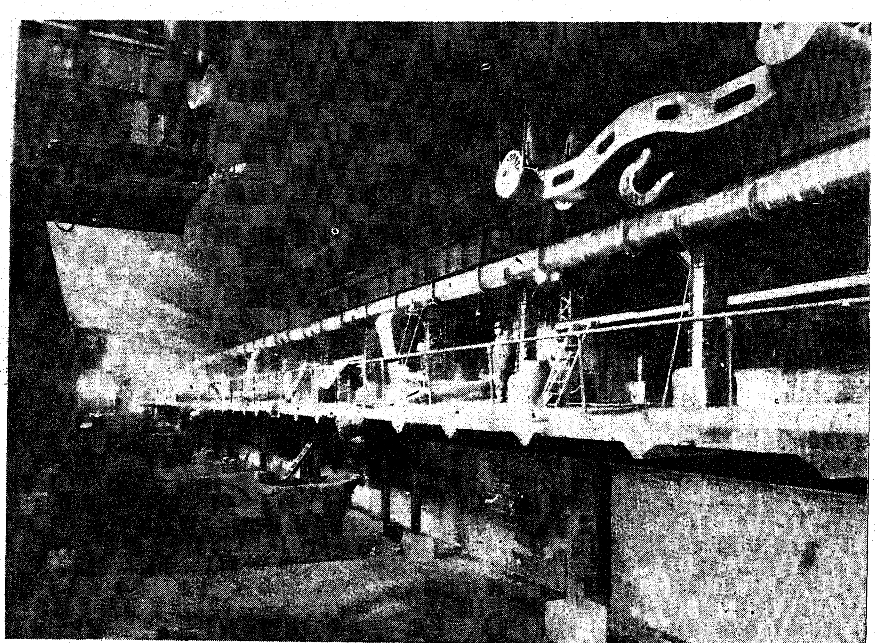


Fig. 70—Blast Furnace Tapping Floor, Copper Cliff.

to form almost self-fluxing mixtures, but when the ore has been insufficiently roasted, a further oxidation must be carried out in the furnace, and to this end quartz is added to the charge. The rapidity of the smelting is thereby decreased, and as much as 50 per cent. of the iron and sulphur can be oxidized, resulting in the formation of a very basic slag with about 55 per cent. ferrous oxide. This slag may often be found in a crystalline condition in the slag dump.

If the furnaces commence to bridge or form accretions in the walls, due to the use of too much fines or silicious ore, limestone is added to the charge to increase the fusibility of the slag; green ore is often added also for the same purpose. If much alumina is present in the ore, a small quantity of limestone is necessary for good working. The proportions in which the various constituents are used is best illustrated by stating the average charge for the year 1915-1916:—

	Percentage of charge to blast furnace.
Roast ore	62.2
Raw Creighton	9.8
Raw Crean Hill	8.7
Total ore	80.7
Converter slag	16.7
Converter scrap	1.7
Limestone	0 4
Quartz	0 5
	100.0
Coke	11.0
Liquid converter slag (poured into settlers)	4.7

The re-smelting of the converter slag has now been abandoned, as the losses of nickel and copper, which are due almost entirely to suspended matte, are found to be avoided by pouring the converter slag into the settlers used for the blast and reverberatory furnace slags.

The following partial analyses represent the general composition of the above constituents, and of the furnace products:—

Composition of Blast Furnace Charge and Products

—	Cu. p.c.	Ni. p.c.	Fe. p.c.	S. p.c.	SiO_2 p.c.	Al_2O_3 p.c.	CaO. p.c.	MgO. p.c.
Roast Ore	1.40	4.10	38.50	11.75	20.25	4.50	2.25	2.50
Raw Creighton Ore	1.40	3.90	39.50	23.00	21.00	5.25	2.50	3.00
Raw Crean Hill Ore	2.50	1.75	24.00	11.50	32.00	10.00	5.00	5.50
Converter Slag	1.00	3.00	47.00	2.40	26.75	3.00	1.25	1.50
Converter Scrap	6.75	14.50	41.00	15.00	9.50	2.50	1.20	1.30
Limestone	....	....	1.00	....	2.50	....	52.75	1.10
Quartz	....	....	3.00	....	91.00	2.90	1.00	1.00
Blast Furnace Matte	7.35	16.86	45.50	26.00	....	....	....	.....
Blast Furnace Slag	0.16	0.32	40.06	1.25	32.09	7.53	3.70	2.50

The introduction of a settler of large capacity as compared with smaller ones in previous service, has led to a 20 per cent. reduction in the nickel-copper content of the slag. Under present conditions, about 9 per cent. of the copper-nickel content of the charge is lost in the slag. The loss increases as the grade of the matte rises, in the following ratio:—

Per Cent. Ni. in Matte.	Per Cent. Ni. in Slag.
15	0.37
20	0.41
25	0.48
30	0.56
35	0 64

The operation is so conducted as to yield a matte averaging 25 per cent. in copper plus nickel. The ratio of the two valuable metals in the matte is determined by the ores used; thus in 1915, the ores contained 2.25 parts nickel for each part copper, the corresponding ratio in the matte being 2.14 to 1. The ratio has been

surprisingly constant over a period of years. In charging, the coke is dumped in first, then the quartz or limestone, followed by the ore, and finally the converter scrap and slag; the quantity put into a furnace at one time is usually about 8 tons, an interval of 20 to 30 minutes elasping before the next charge is added. The height of charge in the furnace is low, averaging 8 feet above the tuyeres.

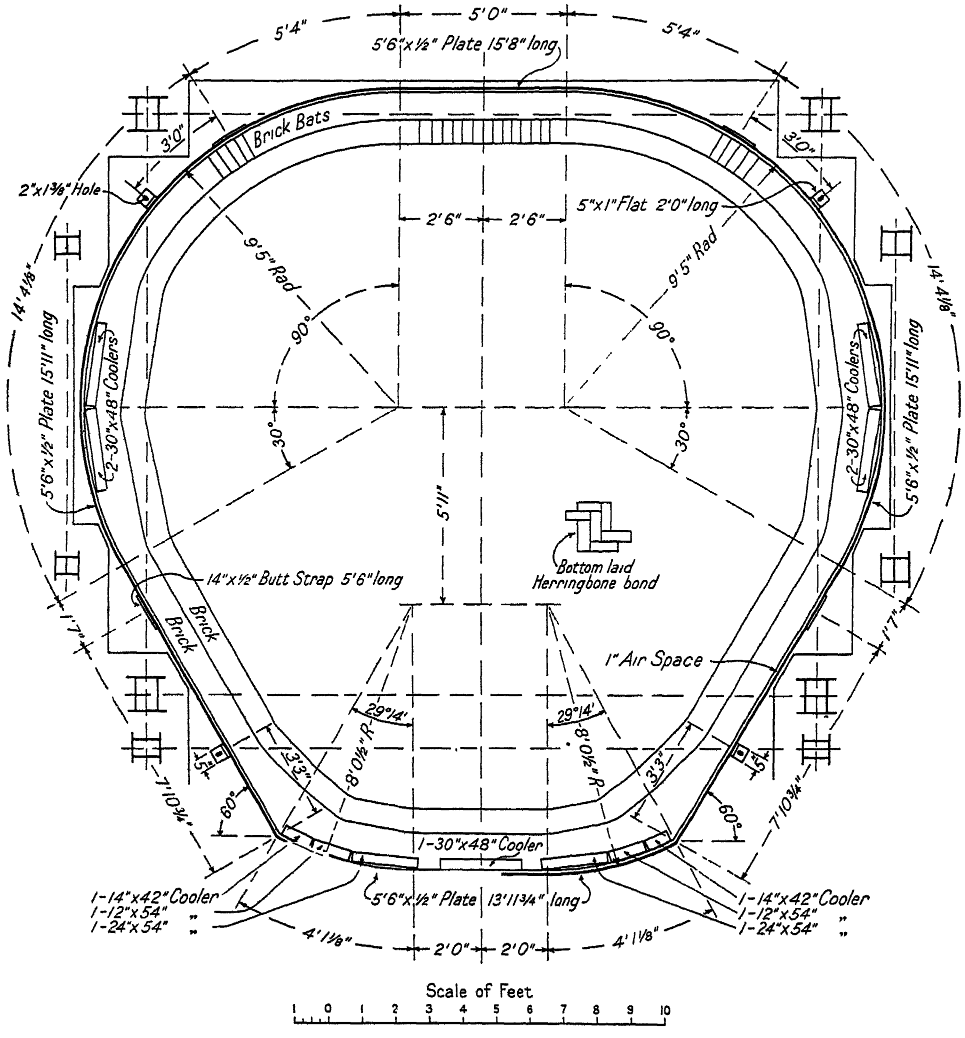


Fig. 71—Plan of Blast Furnace Settler, Canadian Copper Company, Copper Cliff, Ont.

The smelting results in two products, matte and slag, both of which flow continuously through suitable openings into the settlers. The combined output of the 7 furnaces in 1916 was approximately 175 tons of matte per day. For analyses of these products see page 436.

The average concentration attained in 1915-1916 was 100 ore to 22.7 matte, the latter containing 86 per cent. of the metal contents of the charge; the slag produced during the same period equalled 98 per cent. of the ore and contained 9.2 per cent. of the metal contents of the charge. Of the total sulphur in the charge, 44 per cent. is oxidized in the furnace.

Reverberatory Furnaces

In the smelting operations at the plant of the Canadian Copper Company, it is necessary to handle large quantities of fine ore and flue dust. The difficulties which lie in the way of briquetting or sintering these materials, led to the installation of a reverberatory furnace, which has proved very satisfactory. A detailed description of the construction and operation of this furnace has been given by D. H. Browne,[1] from which source the following account has been partly compiled and partly quoted verbatim.

The furnaces are placed on raised blocks of poured slag, 11 feet above the yard level, in order that tappings may be made directly into the pots. Each furnace occupies an area of 23 feet 6 inches by 116 feet 9 inches outside the brick work.

At the fire end, the height of the arch above the hearth inside at the centre, is 7 feet 9¾ inches to 7 feet 11¾ inches, and about 6 feet 8 inches above the skim line.

The height of arch is maintained for a length of 34 feet from the outside of the fire wall. In the next 12 feet the arch drops 1 foot 10¾ inches, giving a height of 5 feet 11 inches to 6 feet 1 inch above the top of the hearth, and about 4 feet 10 inches above the skim line. This height is continued straight through to the throat of the furnace. The roof is 20 in. silica brick for the first 46 ft., and of 15 in. silica brick for the remainder.

The side walls are continuous of 22½ in. silica brick, without side doors. The hearth is silica sand, tamped to place, 24 in. thick at the end walls, and 22 in. thick at the tap hole, which is 36 feet from the fire wall.

The side walls, built as described, are carried straight to a point 26 ft. from the throat, where they curve inward, the space of 19 ft. 9 in. between them being narrowed up along a line of gradually increasing curvature to a width of 8 ft. 8 in. at the throat. At this point the opening is 4 ft. 3 in. high at the centre and 3 ft. 9 in. high at the sides. The arch here is about 4 ft. 8 in above the skimming line.

From the throat a straight flue 8 ft. 8 in. wide leads to the waste-heat boilers and to the stack. Openings are provided along the side of this flue for cleaning out any deposited ash. An opening opposite to the throat is provided by raising the bottom of this flue about 18 in. above the throat and introducing a door in the space thus formed. This is very useful for removing any accretions of ash fused in the throat. The skimming door is placed on one side of the furnace, 16 ft. 6 in. back from the throat. This door, 2 ft. 6 in wide by 15 in. high, allows slag to run off down to a skimming line 14½ in. above the hearth at the tap hole. The slag can rise 6 in. above this line before reaching the level of the side doors now bricked up. Outside the skimming door a cast-iron clay-lined box is provided to trap any matte carried over. From this a cast-iron slag launder curves to a line almost parallel with the furnace, and delivers the slag into 25-ton pots, which are brought in on a track at right angles to the furnace under the flue.

Feeding the Furnace

The furnace is fed in a rather peculiar way. When the furnace was started almost all the charge was introduced through two charge hoppers near the fire end, as in the usual Western practice. The first hopper delivered through two openings 11 in. in diameter, 7 ft. 6 in. apart and 8 ft. from the outside of the fire wall. The second hopper delivered through two similar openings 18 ft. from the fire wall.

[1] Bull. Amer. Inst. Min. Eng., January, 1915.

At present almost all the charge is introduced through hoppers along the side walls. Directly over the side walls, at the fire end of the furnace, large bins are provided, which discharge into small bottom-dump cars. These cars run on 24-in. tracks, which are supported from overhead. Under these tracks a long trough extends down each side of the furnace just above the side walls. These troughs are filled from the cars on the track above them. Each trough has openings in the bottom, 2 ft. apart, which openings communicate by a slide gate with 6-in. iron pipes. These pipes pass into holes drilled in the roof bricks, which allow the charge introduced through these openings to slide down on the side walls, over which this charge forms an almost continuous blanket. As there are no doors on the furnace, and as the 6-in. pipes are clayed into the openings in the roof, it follows that no air is introduced into the furnace except what is purposely introduced at the fire end.

These pipes form a continuous line of charging holes, which extend the entire length of the furnace. The charge on the side opposite the slag door is fed all the way to the throat. On the slag side it is fed along as far as the slag door and no farther, as the cold air coming in while skimming cools the wall from the skim door to the throat, and obviates the necessity of charging beyond this point. Six similar openings are used on the fire wall.

The walls are held in place by 12-in. I-beams in pairs, with a space of 5 ft. between each pair, which form the side braces. These are wedged in at the bottom by wooden wedges against an iron strap in the concrete footings. The concrete footings are tied together as previously described by rods passing under the furnace. At the upper end the 12-in. I-beams are tied across the furnace by 1½ in. rods.

Coal Dust Firing

The coal dust is introduced through five pipes, 5 in. in diameter. One of these pipes is on the centre line of the furnace; the others are in horizontal line with it at distances of 3 ft. 3 in. from centre to centre. These pipes are 5 ft. 2 in. above the bottom of the sand hearth, or 3 ft. 2 in. above the top of this hearth. They are about 2 ft. above the skimming line of the charge, and the central pipe is about 4 ft. 8 in. below the highest point of the roof.

The maximum bath of matte and slag is 22 in. deep. A constant bath of 8 in. of matte is carried. This matte lies 6 in. below the skimming plate, so that after skimming there are 6 in. of slag and 8 in. of matte left in the furnace, making a total minimum depth of 14 in. The skimming door is banked up 8 in. with sand, so that just before skimming the slag is 14 in. deep. As the charge along the side walls occupies a great deal of room there is never at any time more than 40 or 50 tons of slag in the furnace.

In rebuilding this reverberatory, or in designing a new plant, the hearth should be widened to provide for a larger body of matte, which experience has shown to be necessary. As this method of burning coal and of admitting the charge into the furnace, bids fair to come into general use, it is to be expected that many changes, both in construction and operation, will be introduced. My belief is that reverberatory smelting along these lines will become cheaper than blast-furnace smelting, and that a wider range of ores can be used in such a furnace than in the old-style coal or oil-fuel furnaces.

The coal used in firing is a good quality of slack. Analysis of one lot showed: Volatile matter, 34.70; fixed carbon, 55.40; ash, 9.45; sulphur, 1.30; moisture, 4.31 per cent.

This coal has a thermal value of about 13,500 b.t.u. per pound. It is about ¾ in. and under in size, and contains about 7 per cent. moisture. It is dried in a Ruggles-Coles drier, 70 in. in diameter and 35 ft. long. One ton of coal burned on the grate dries 40 to 50 tons of slack coal to about 5 per cent. moisture, which falls to 2.4 per cent. moisture after grinding. About 10 tons of slack is dried per hour of running time. The coal is ground in Raymond impact mills. About 95 per cent. passes a 100-mesh and 80 per cent. passes a 200-mesh screen.

The pulverized coal is sucked by a fan to separators above the roof of the drier building, and slides down into a screw conveyor, which delivers it into bins at the fire end of the reverberatory. The dust is fed from these bins by Sturtevant automatic-feed screw conveyors, one for each nozzle, the speed of which can be regulated. These screws carry the dust forward, and drop it into the air nozzles about 2 ft. from the point where the nozzles enter the furnace. Any coal-delivery pipe can be closed off by a slide gate, and any screw conveyor can be stopped by disconnecting the bevel gears attached thereto. In this way any desired number of the five burners can be run, and at any desired speed within wide limits. The amount of air delivered to each nozzle can be varied at will or cut off entirely.

As a rule the five burners are in operation. Each delivers about 13.5 tons of coal dust a day, or about 19 lb. of coal per minute to the furnace. The total coal blown in is about 67 tons a day.

The dust drops from the conveyors into the air pipes, which carry it forward into the furnace. The air is supplied by a 4-ft. Sturtevant fan, running at about 1,300 to 1,400 revolutions per minute. The air supplied by this fan is insufficient for the combustion of the fuel. Openings are left in the end wall between the coal burners. These openings are stopped by loose bricks, so that the amount of air is readily controlled. The draft at the

fire wall is about 0.25 in. of water and at the throat it has a maximum of about 1.2 in. The combustion is very good. One test made for 10 days (Jan. 9 to 19, 1914) showed the following averages:

Coal consumption, tons in 24 hours	69.7
Gas temperature at throat, degrees centigrade	922
So_2 and CO_2, per cent.	12.3
Oxygen, per cent.	6.5
SO_3, per cent.	1.14

During this test the average charge was 409 tons in 24 hours. This shows a ratio of 5.9 parts charge to 1 part coal, but much higher ratios have been attained. The average for March, 1914, was 6.84. This coal ratio depends largely upon the composition of the charge, and the analysis of the slag produced.

A criticism might be made of the low temperature of the gases at the throat, 922°C. The usual practice in Western smelters is to carry a temperature of 1,200° to 1,300° at this point, and it might be thought that this low temperature indicated inefficient firing. The fact is that the heat of combustion is utilized in smelting ore along the side walls and consequently the escaping gases, having done more work than is usually the case, are relatively cold. The function of a reverberatory furnace is to melt ore, not to raise steam, and for this reason the more heat that is absorbed from the coal gases in the furnace, the more efficient the operation, and the cooler the escaping gases.

The ash from this coal causes very little trouble in operating. A small amount settles on the slag, but as this slag is high in iron it is not an undesirable feature. A small amount also settles in the flue, and a few hundred pounds may stick around the throat. The ash, where exposed to high heat, forms a very light pumice-like fragile mass. The throat is cleaned out daily by opening the door under the flue. During this cleaning the firing is maintained as usual.

The great advantage of coal-dust firing is the absence of the usual breaks in the temperature curve due to grating or cleaning the hearth, and as a consequence a greatly increased tonnage and fuel ratio. The operation of firing, being purely mechanical, comes under the immediate and direct control of the furnace foreman, and responds instantly to his regulation. In addition to this, the peculiar method of feeding by almost continuous side charging obviates the breaks in the temperature curve due to charging or ordinary fettling. For these two reasons the chart of the temperature shows an almost horizontal line, rising or falling in almost exact concordance with the speed of the coal-feeding device.

Charge Employed in Reverberatory Furnace

The average charge to a reverberatory furnace is as follows:—

	Per Cent.
Wedge calcines and wedge flue dust	64 0
Raw Creighton fines	2.0
Raw Crean Hill fines	21.7
Total ore	87.7
Blast furnace flue dust	12.3
	100.0
Coal burned	22 5

If necessary sand is added as a flux.

Approximate average analyses of the raw materials and products for three years ending 1915, are given below:—

Composition of Reverberatory Furnace Charge and Products

—	Cu. p.c.	Ni. p.c.	Fe. p.c.	S. p.c.	SiO_2 p.c.	Al_2O_3 p.c.	CaO. p.c.	MgO. p.c.
Wedge calcines	1.75	3.85	36.50	7.00	27.00	5.00	1.75	2.00
Wedge furnace flue dust	1.85	3.00	23.00	11.00	23.50	8.75	3.50	3.75
Raw Creighton fines	1.60	3.95	38.00	22.75	20.00	4.50	2.25	2.50
Raw Crean Hill fines	2.90	1.85	24.75	12.75	30.50	9.25	4.25	4.50
Blast furnace flue dust	1.70	3.70	39.00	10.50	21.00	4.50	2.40	2.70
Reverberatory matte	9.75	14.50	44.75	27.50	....	....	....	....
Reverberatory slag	0.21	0.40	34.50	0.60	36.00	6.00	3.00	2.50

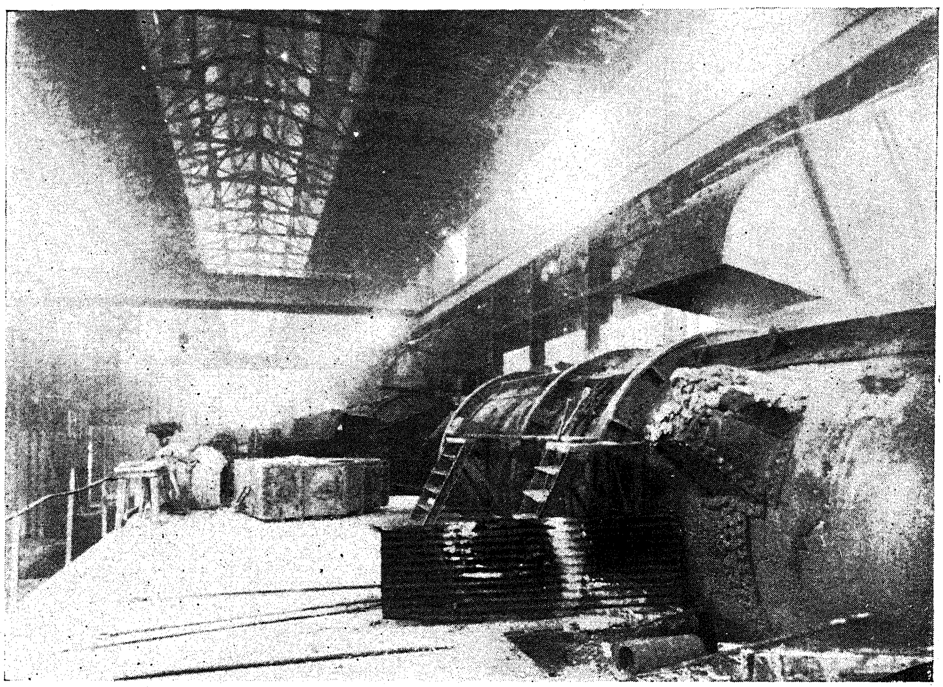


Fig. 72—Interior of Converter Building, Canadian Copper Company, Copper Cliff, Ontario.

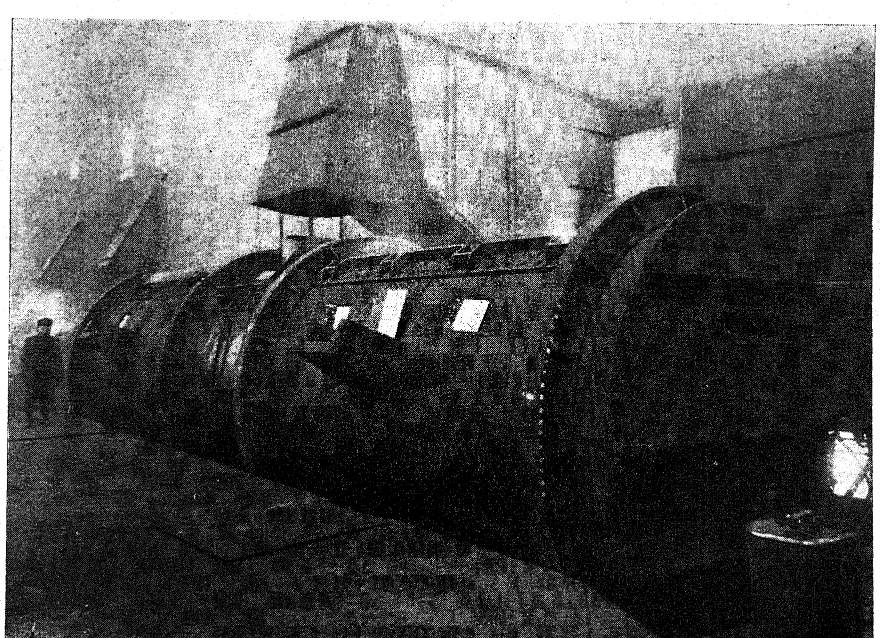


Fig. 73—Converter, Canadian Copper Company, Copper Cliff, Ontario.

The weight of matte produced in 1915-1916 averaged 18.7 per cent. of the charge, or 21.3 per cent. of the ore, while 82.6 per cent. of the copper plus nickel content of the ore was recovered in the matte. Similarly the slag weighed 81 per cent. of the charge or 93 per cent. of the ore, and contained 10.5 per cent. of the copper plus nickel of the ore. Of the total sulphur in the charge, an average of 31 per cent. is oxidized in the reverberatory.

The efficiency as far as the recovery of metals goes, is as follows:—

——	Total Recovery.	Recovery in matte.	Recovery in reverts.	Loss in slag.	Mechanical loss.
Blast furnaces	88.4	86.1	2.3	7.4	4.2
Reverberatory	83.4	82.6	0.8	9.2	7.4

Bessemerizing

The converter plant and its operation has been described by D. H. Browne in a paper read before the Canadian Mining Institute in 1912[1], from which the following account has been prepared, with additional information furnished by the company.

Acid Converters

In the year 1910 the Canadian Copper Company had in operation ten stands of acid converters The shells were 84 in. x 126 in., and were lined with the usual mixture of quartz and clay. In each shell were eight tuyeres, one inch in diameter and six inches apart. The centre or mould around which the lining was rammed was oval in shape, 3 ft. 4 in. high, 5 ft. x 2 ft. 6 in. at top and 4 ft. 6 in. x 2 ft. at the bottom. Each shell consumed about 3,000 cubic feet of free air per minute at 9 to 11 lbs. pressure.

The production of matte from these shells depended largely on the grade of furnace matte with which they were supplied. On a 36 per cent. furnace matte one lining lasted for about eight hours' blowing time, and produced seven tons of finished bessemer matte, 80 per cent. copper-nickel. On a 30 per cent. furnace matte one lining was good for about 5.3 tons bessemer matte.

As the amount of metal lost in furnace slag depends very much on the grade of furnace matte made, this pointed to the desirability of producing lower grades of furnace matte with cleaner slags. This threw on the converters every year an increasing burden. The converters received lower grade furnace mattes, containing not only less copper-nickel, but more iron. In a 40 per cent. furnace matte one pound of copper-nickel is accompanied by 0.88 lbs. iron, in a 30 per cent. matte by 1.34 lbs. iron, and in a 20 per cent. matte by 2.4 lbs. iron.

As this iron is removed by oxidation and combination with silica to form a slag, and as the amount of air passing into the converter is a fixed factor, practically 3,000 cubic feet per minute, it is evident that lower grade mattes take longer to blow than higher grades. When using a 36 per cent. furnace matte, about one hour and five minutes blowing is required to produce a ton of 80 per cent. bessemer matte, while with a 30 per cent. furnace matte an hour and fifty minutes is required.

Furthermore, the amount of scrap, or material thrown out of the mouth of the converter while blowing, is a factor of the time of blowing. The quantity thrown out by the blast is about the same per hour. Therefore, as the furnace matte becomes of lower and lower grade, the production of the converters becomes less and less, first, because they have more iron to remove and need longer time to do it, and second, because during this longer time they slop out more and more material on the floor.

Basic Converters

These considerations decided the Canadian Copper Company to discard this type of acid converters and to substitute basic converters, such as had been installed by Smith and Pierce at the Garfield plant of the American Smelting and Refining Company.

[1] Trans. Can. Min. Inst., Vol. 15, pp. 115-122.

A basic converter is simply a cylinder lined with magnesite brick. The function of the converter is exactly the same as in the acid converters. Air blown in through the tuyeres passes through melted matte and oxidizes iron. The oxide of iron combines with silica and forms a slag. The difference lies in the fact that in the acid converters, the silicious material is rammed in to form the lining of the converter. The iron attacks this lining and melts it off to get at the silica, so that after a few hours blowing the lining is all cut away and the shell must be relined. In the basic converter the lining consists of basic bricks, and the quartz or other silicious material is dumped into the converter on top of the matte from time to time as the converter requires it. The magnesite bricks which form the lining are very slowly worn away above the tuyeres, but a basic converter will make six or seven

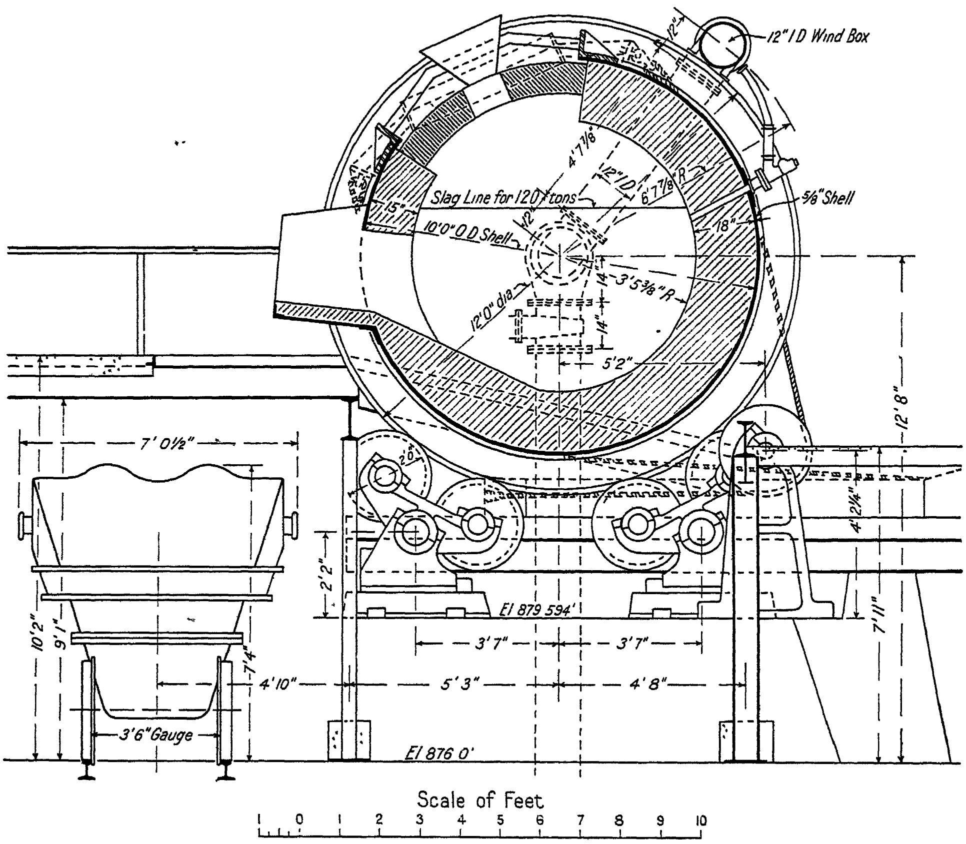


Fig. 74—Cross-section of Converter, Canadian Copper Company, Copper Cliff, Ontario.

thousand tons of bessemer matte before it requires repair, while an acid converter requires relining after making six or seven tons.

In March, 1911, the first basic converter was blown in. During the remainder of the year the acid stands were taken out, and basic converters put in their place. At present all the acid converters have been removed, and their places taken by five basics.

These basic converters are 37 ft. 2 in. long by 10 ft. in diameter, outside measurement. They turn on four tread rings 12 ft. in diameter. The stack or opening in the roof for the escape of gas, is in the centre of the cylinder instead of at the end, as in the Garfield plant. There are 44 tuyeres, 1¼ in. in diameter and 7 in. apart. There are no tuyeres directly under the stack. The length inside the lining is 33 ft 3 in. The bottom is 2 ft. thick, the back or tuyere wall is 18 inches, and the front 15 inches thick. The roof is a 12-inch arch. The brick directly around the tuyeres is 24 inches thick.

These converters have two openings or spouts in the front wall opposite to, but above, the tuyere line. The shell is turned down to pour slag and matte from these openings, or turned back to blow, by means of two wire ropes which surround the shell on either side of the central stack. These ropes are fastened to a hydraulic piston working in a horizontal cylinder, having a stroke of nine feet.

As the usual hydraulic equipment would not be suitable to the climate of Northern Ontario, oil is used instead of water, since oil remains fluid at low temperatures.

The oil is moved in the cylinders by air pressure. Since electric power is used, which is subject to occasional break-down, it is possible that the blast might stop suddenly, and the matte would then find its way into the tuyeres and solidify. To avoid such an occurrence, an emergency tank of oil under pressure is so governed by an electrical control as to turn down the converter automatically till the tuyeres emerge, on any interruption to the power supply. Each converter requires about 6,500 cubic feet of free air per minute at 10½ lbs. pressure, which oxidizes the iron sulphide to iron oxide at the rate of about 120 pounds iron per minute, the corresponding quantity of sulphur dioxide being liberated.

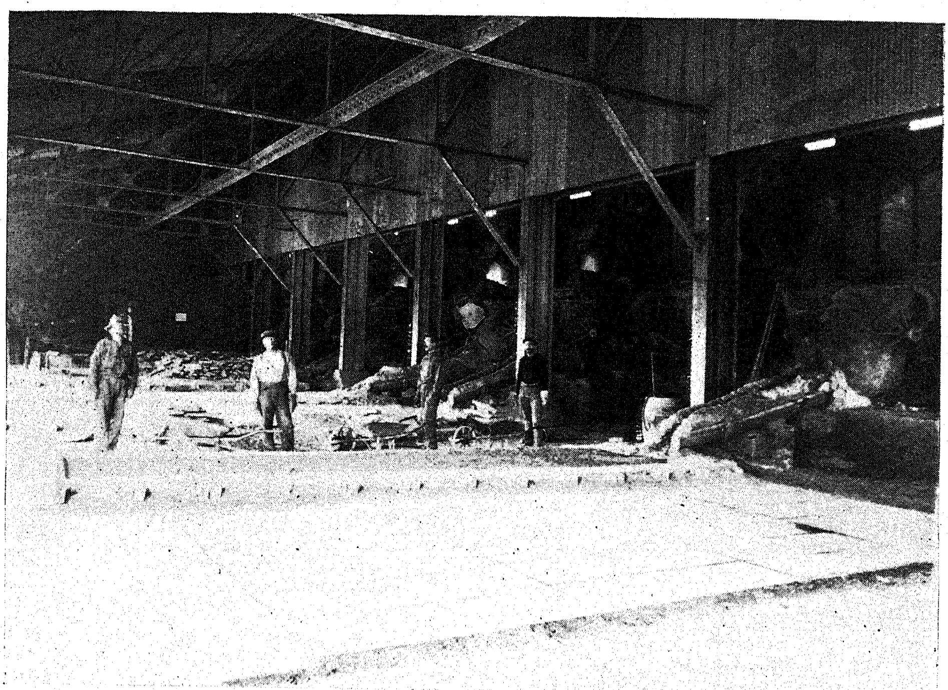


Fig. 75—Floor Moulds for Converter Matte, Canadian Copper Company, Copper Cliff.

Charge for Converter

In commencing a fresh "blow," about 70 tons of blast furnace and reverberatory matte is poured in by ladle, and 10 per cent. silicious flux is added; the blast is then turned on and maintained for one-half to three-quarters of an hour. The "blowing" is always carried on for a definite interval of time, as distinguished from the operation of the Bessemer converter in the steel industry. At the end of the first period, the slag is poured off, and another 5 or 6 tons of matte is added simultaneously.

When the slag has been removed about three tons of silicious flux is added, and "blowing" commences once more. This cycle of operations is continued until about 400 tons of matte and 158 tons of flux have been charged, and 117 tons of bessemer matte remain in the shell; about 52 hours is required to reach this stage, during which, "blowing" has been carried on for 34 hours. "The length of blow, the amount of slag removed, the weight of matte added after each skim, and the per cent. of flux required, are all factors of the gràde of matte, and have to be determined by experience."

A typical charge would be:—

Blast furnace matte	380 tons
Reverberatory matte	46 "
Scrap from ladles, etc.	25 "
Creighton rock	96 "
Quartz rock	83 "

Average analyses of these constituents and of the products of the converter are given in the following table:—

Composition of Converter Charge and Products

—	Cu. p.c.	Ni. p.c.	Fe. p.c.	S. p.c.	SiO_2 p.c.	Al_2O_3 p.c.	CaO. p.c.	MgO. p.c.
Blast furnace matte	7.35	16.86	45.50	26.00	....	....	....	....
Reverberatory matte	9.75	14.50	44.75	27.50	....	....	....	....
Scrap from ladles, etc.	6.75	14.50	41.00	15.00	9.50	2.50	1.20	1.30
Creighton Rock	0.50	0.60	12.50	3.50	52.00	13.00	4.50	4.60
Quartz	....	....	3.00	....	91.00	2.90	1.00	1.00
Converter matte	25.00	53.50	0.40	21.25	0.05	....	....	....
Converter slag	1.00	3.00	47.00	2.40	26.75	3.00	1.25	1.50

The ratio of the blast furnace matte to that from the reverberatory is dependent upon the quantities derived from the two sources in the daily operation; it is as a rule about eight of the former to one of the latter.

The flux consists of a mixture of 45 per cent. quartz and 55 per cent. mine rock, the latter carrying about 1 per cent. of copper plus nickel; the mixed flux contains approximately 70 per cent. of silica. An average of 180 tons of iron is oxidized and slagged off in one converter charge.

In converter practice, a matte of 50 to 55 per cent. nickel (48 to 55 per cent. is usually attained) and 25 to 30 per cent. copper is desired; as much iron is to be removed, and as much sulphur is to be left in as possible, in order that the matte may be high grade and still brittle. If more than 80 per cent. nickel plus copper be present in the matte, toughness develops, and subsequent breaking is rendered difficult. The concentration is 100 tons of blast furnace and reverberatory matte to form 24 to 28 tons of finished 80 per cent. or bessemer matte. The elimination of practically all of the iron and of much of the sulphur in the crude furnace matte is very evident from the analysis in the table given above.

The converter slag, averaging 1 per cent. copper and 3 per cent. nickel, was formerly re-smelted in the blast furnace, but is now merely poured into the settlers. Since the slag going to the dump only carries 0.16 per cent. copper and 0.32 per cent. nickel, the efficiency of the settling process is obvious.

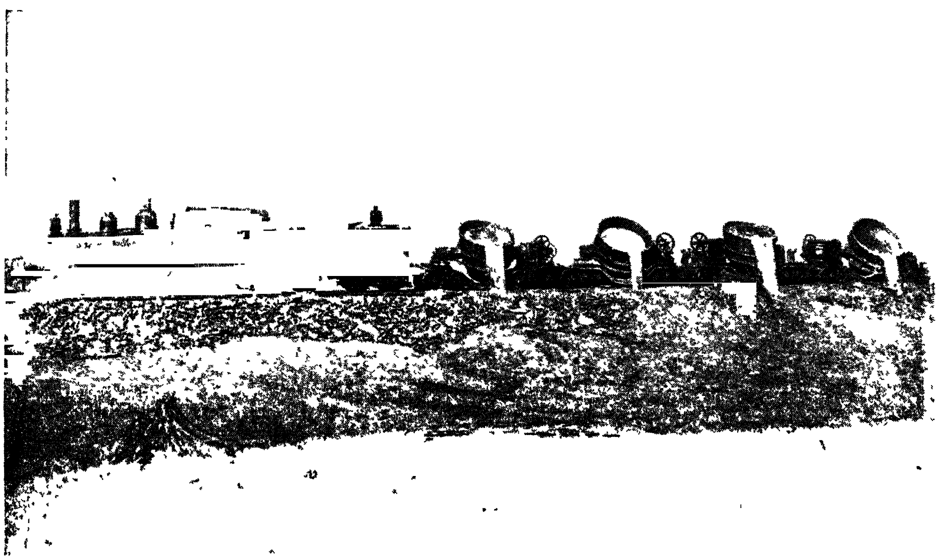


Fig. 76—Pouring Slag on Dump, Canadian Copper Company, Copper Cliff, Ontario.

The following table shows the production of Bessemer matte, by the Canadian Copper Company, during the past ten years, together with the assays and losses in smelting:—

Bessemer Matte Production, Canadian Copper Company, with Assays and Smelting Losses

Year ending March 31st	Bessemer Matte				Smelting Loss			
	Production Tons	Assay		Tons ore smelted per ton matte produced	Proportion of total in ore		Slag assay	
		Ni. per cent.	Cu. per cent.		Ni. per cent.	Cu. per cent.	Ni. per cent.	Cu. per cent.
1907	17,840	56.07	22.72	17.02	27.09	20.67	0.55	0.24
1908	18,839	46.78	33.29	16.11	27 29	17.98	....	....
1909	18,407	47.14	33.06	17.06	22.14	15.14	0.42	0.22
1910	24,309	54.39	25.69	17.01	20.37	15.67	0.40	0.19
1911	26,840	55.62	24.99	17.24	18.16	13.88	0.38	0.18
1912	27,653	54.42	24.76	17.16	14.22	15.96	0.33	0.17
1913	38,733	56.31	23.66	16.442	17.01	18.48	0.36	0.19
1914	40,267	53.89	25.94	17.351	16.10	13.01	0.30	0.15
1915	31,428	53.66	25.18	18.301	15.49	14.47	0.33	0.16
1916	56,405	53.52	24.99	17.745	15.88	12.85	0.33	0.16

Power

Electric power is obtained from the plant at High Falls, Spanish river, beyond the Worthington mine. These falls are owned by the Huronian Power Company; the whole equipment is fully described in the chapter dealing with Mining Methods.

The Mond Nickel Company

The first smelting plant operated by this company was situated at Victoria Mines, twenty-two miles west of Sudbury on the Sault Ste. Marie branch of the Canadian Pacific railway. The ore was brought from Victoria mine, two miles away, by an aerial tramway, the roast yards being halfway between the mine and the smelter.

The plant as originally built in 1901, had a capacity of about 60,000 tons of ore per year, and was operated by steam until May, 1909. Electric power was then

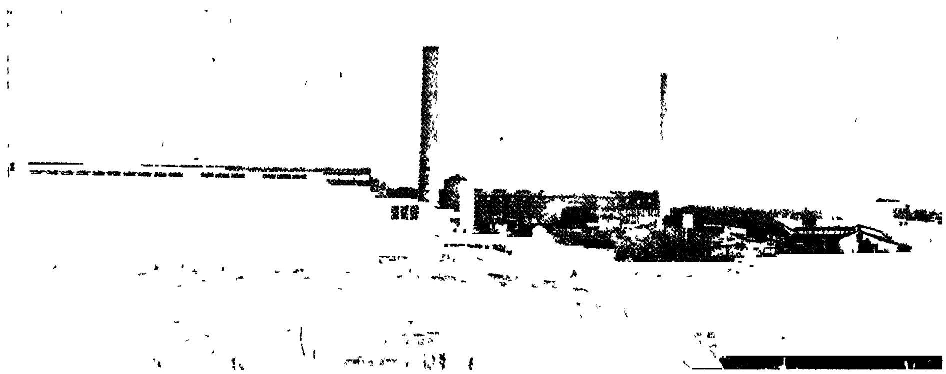


Fig. 77—General View of Coniston Plant, 1914, Mond Nickel Company, Ontario.

introduced, and the capacity was increased to 140,000 tons, but without enlargement of the furnace and converter building. Since Victoria Mines was served by only one line of railway, and was also at a considerable distance from the other mines of the company, the selection of a more central site for the smelting plant appeared to be desirable. After careful investigation the present site at Coniston was selected, where three lines of railway are available—the main line and the Toronto branch of the Canadian Pacific railway, and the main line of the Canadian Northern railway.

The ore as mined is passed over grizzlies, and hand-sorted on belts or tables, the coarse material being then divided into waste, concentrating ore, and direct smelting ore. This last product is variously treated, for the direct smelting ore from the Garson and Worthington mines goes to the smelter bins for raw smelting, while that from Levack and Victoria mines is roasted in heaps in the Coniston roast yard. Part of the concentrating ore is at present treated at Coniston in an experimental plant using tables and oil flotation, and the balance is placed on stock piles for future treatment.

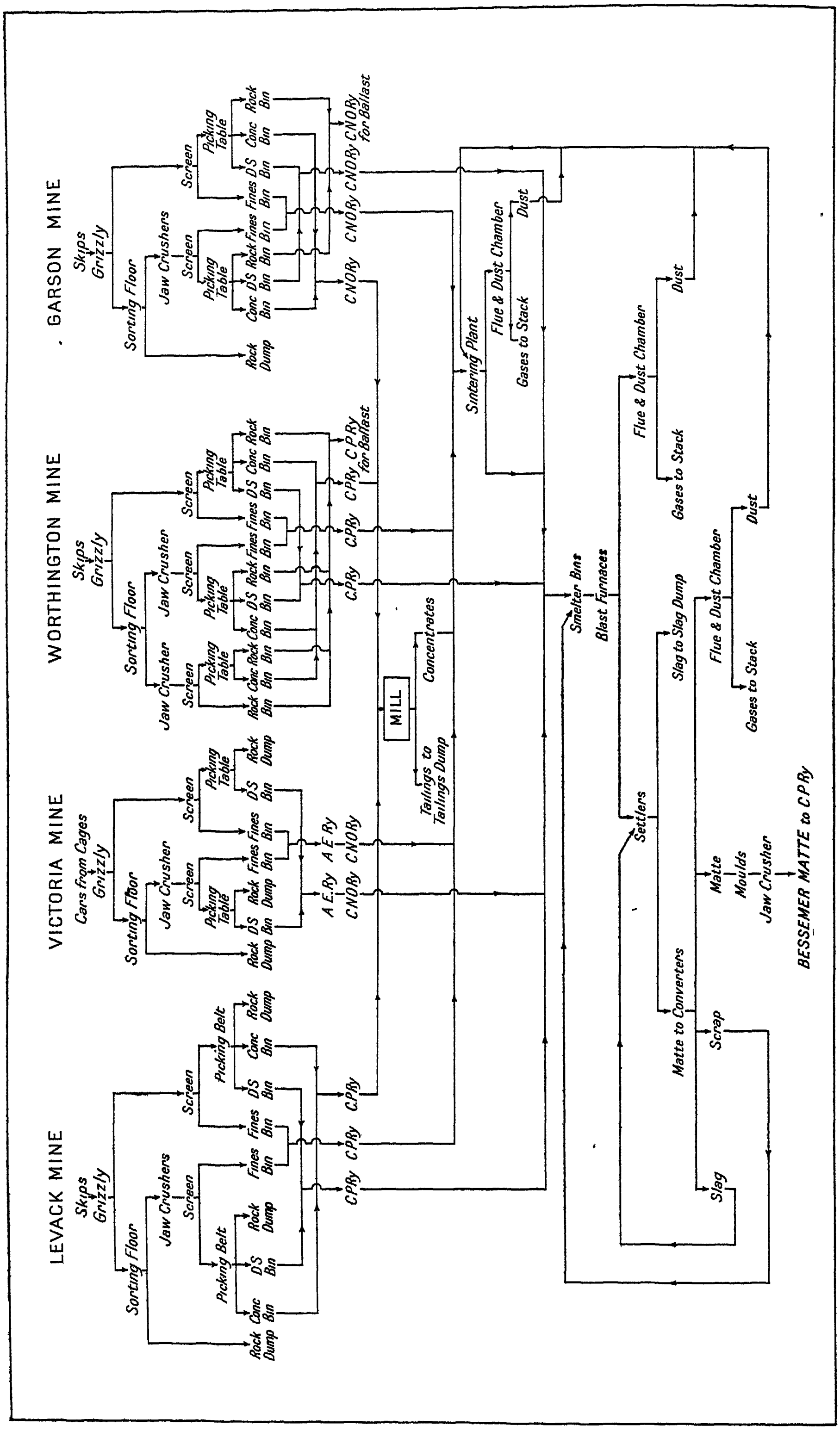


Fig. 78—Flow-sheet, Mond Nickel Company, Coniston, Ontario.

The accompanying flow-sheet (Fig. 78) shows diagramatically the whole treatment from the mine skips to the bessemerized matte as at present carried out, but with roast heaps eliminated.

Roast Heap Practice

Of the ore smelted at the Coniston plant, about 30 per cent. is roasted in open heaps in the same manner as at Copper Cliff, which has been described above. The roast yard, which lies about three-quarters of a mile southeast of the smelter, has a capacity of 40 heaps, each 120 ft. long, 32 ft. wide, 9 ft. deep, holding 2,000 to 2,500 tons of ore, making a total of 100,000 tons; the amount of ore in the yard at one time varies from 60,000 to 100,000 tons.

Roasting requires about three months or, if the time required for building the beds and cooling be added, five months is necessary. Considerable alterations in practice, as described on page 428, are being made by the company with a view to the abandonment of heap roasting.

Mechanical Roasting

The balance of the fines which is not required for covering the heaps in the roast yard, amounting to 15 to 20 per cent. of the total ore, is sintered in two Dwight-Lloyd straight line machines. Fuel oil is used as an igniter; the charge is about five minutes in passing over the exhaust wind boxes and three minutes in cooling beyond the wind boxes before the sinter is broken off the grate; the product contains about 7 per cent. sulphur.

Smelting Plant

There are in use at present, three blast furnaces of the rectagular water-jacketed type 50 by 240 in. at the tuyeres, each with a capacity of 420 tons of ore per 24 hours. The charge is carried to 12 feet above the tuyeres, and the blast is about 25,000 cu. ft. of air per minute at 32 oz. pressure. The matte and slag flow into three settlers, one of which is 20 ft., the other two 16 ft. in diameter, all 5 feet deep and lined with 12 in. of chrome brick. From the settlers, the slag is hauled in standard gauge slag cars to the dump, while the matte is tapped into ladles and transferred by travelling cranes to the converters.

The power house contains four Connersville blowers of 140,000 cu. ft. of air per minute for the furnaces, and two blowing engines of 18,000 cu. ft. per minute combined capacity for the converters.

The general arrangement of the plant is shown in Figure 79.

Smelting Operations

The smelting practice of this company is very similar to that of the Canadian Copper Company. The chief point of difference lies in the use by the Mond Company of a larger proportion of green ore; thus, in average charges, the Mond Nickel Company take 55 per cent. of roasted ore, and the Canadian Copper Company 77 per

cent. This is partly due to the fact that the ores of Mond Nickel Company are lower in sulphur, and partly to the fact that this company carries out a modified pyritic smelting.

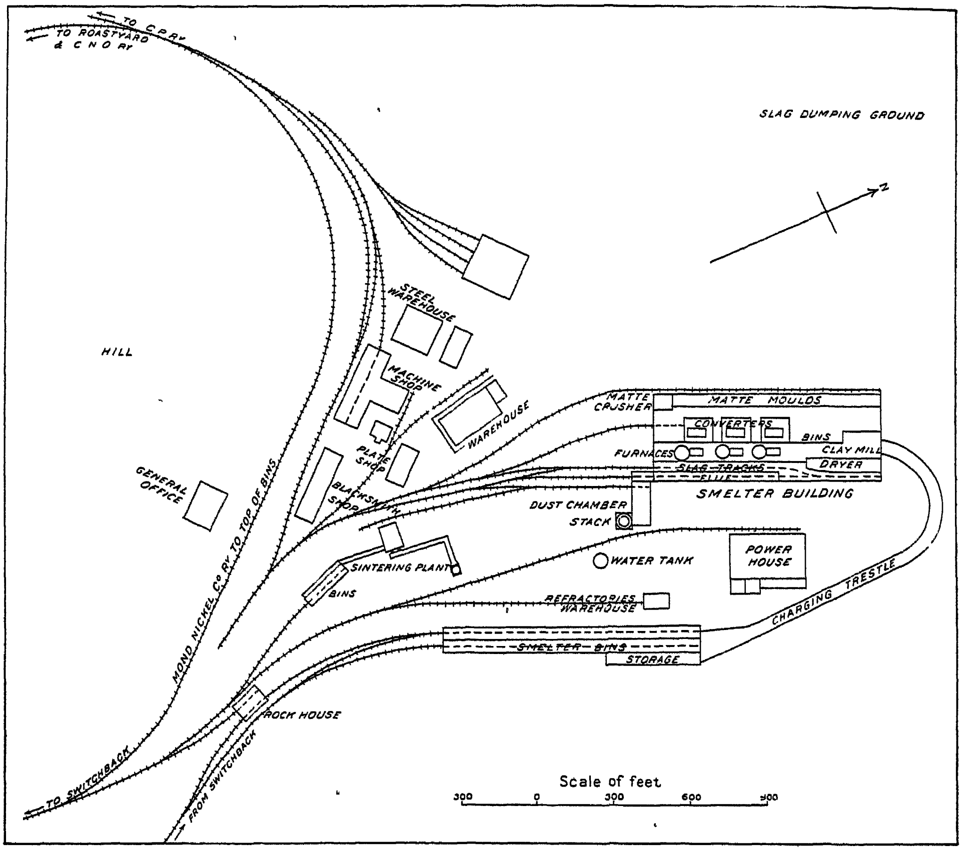


Fig. 79—Plan of Smelter and Adjacent Buildings, Mond Nickel Company, Coniston, Ontario.

A typical charge at Coniston would be:—

Roasted ore and sinter	10,000 lbs.
Raw ore	8,000 "
Scrap	2,000 "
Limestone	2,200 "
Total	22,200 "
Coke	2,200 "
	24,400 "

Average analyses of the various constituents and of the matte and slag produced, are given in the following table:—

Analyses of Smelting Charges and Products

—	Cu. p.c.	Ni. p.c.	Fe. p.c.	S. p.c.	SiO_2 p.c.	Al_2O_3 p.c.	CaO. p.c.	Mgo. p.c.	Insol. p.c.
Direct smelting ore:—									
Levack	0.5	2.8	45.0	23.7	13.5	4.8	2.2	1.3	21.2
Garson	1.9	2.3	29.1	17.2	26.8	9.0	3.4	4.2	35.7
Kirkwood	1.5	3.2	42.9	24.9	13.2	4.8	2.0	2.2	21.4
Worthington	3.4	3.0	26.0	17.0	29.0	6.0	3.8	7.0	45.0
Victoria	3.4	1.9	40.2	22.6	17.0	5.1	2.3	1.5	23.3
Garson quartz	1.1	0.5	10.7	4.8	59.9	9.0	2.9	4.4	67.5
Bruce Mine tailings	1.0	0.0	2.7	1.1	88.5	2.5	0.5	1.2	90.6
Roasted ore	2.2	2.1	32.4	9.7	25.9	8.8	3.4	3.5	34.9
Sinter	2.7	2.8	30.5	6.9	30.0	7.9	4.4	5.7	45.9
Limestone	......	......	0.5	......	2.5	0.2	52.6	0.7	2.6
Blast furnace matte	9.0	11.0	48.0	25.0	......	......	......	......	......
" " slag	0.17	0.22	26.6	0.9	34.7	10.1	13.7	5.3	......
Bessemer matte	41.0	41.0	0.6	17.0	......	......	......	......	......
Converter slag	0.7	1.3	45.4	1.4	32.1	2.4	1.0	1.1	......
Slag from settlers, blast furnace and converter	0.20	0.29	29.9	0.9	34.2	8.7	11.3	4.5	......

A matte with 20 per cent. nickel plus copper is considered to be the most economical; 275 tons are produced per 24 hours. The concentration is about 100 of ore to 23 of matte.

No reverberatory furnaces are used by the Mond Nickel Company. The flue dust and fines are sintered in the Dwight-Lloyd furnace.

Converter Practice

The converter department is equipped with three standard Pierce-Smith basic converters each 25 ft. long by 10 ft. diameter outside, or about 22 ft. long and 7 ft. inside the brickwork.

The blast furnace matte drawn from the settlers into ladles, is transferred to the converter by a travelling crane, until 30 or 40 tons has been introduced together with some quartz flux. The latter is usually provided in the form of tailings from Bruce Mines, which contains about 1 per cent. copper as chalcopyrite, and over 88 per cent. silica, together with Garson mine quartz, which also contains about 1 per cent. copper and 0.5 per cent. nickel, but which carries under 60 per cent. of silica. Blowing at the rate of 5,000 to 7,000 cu. ft. of air per minute under a pressure of 10 lbs., is carried on for an hour, after which the slag is skimmed and six tons of furnace matte and two and one-half tons of flux are added. Blowing is then continued for an hour, followed by skimming of the slag, and the addition of a further portion of the charge.

This process goes on for twenty to thirty hours until there is in the converter thirty or forty tons of bessemer matte. The charge is then finished, that is, blown until almost all the iron is eliminated. The finished matte is poured into ladles

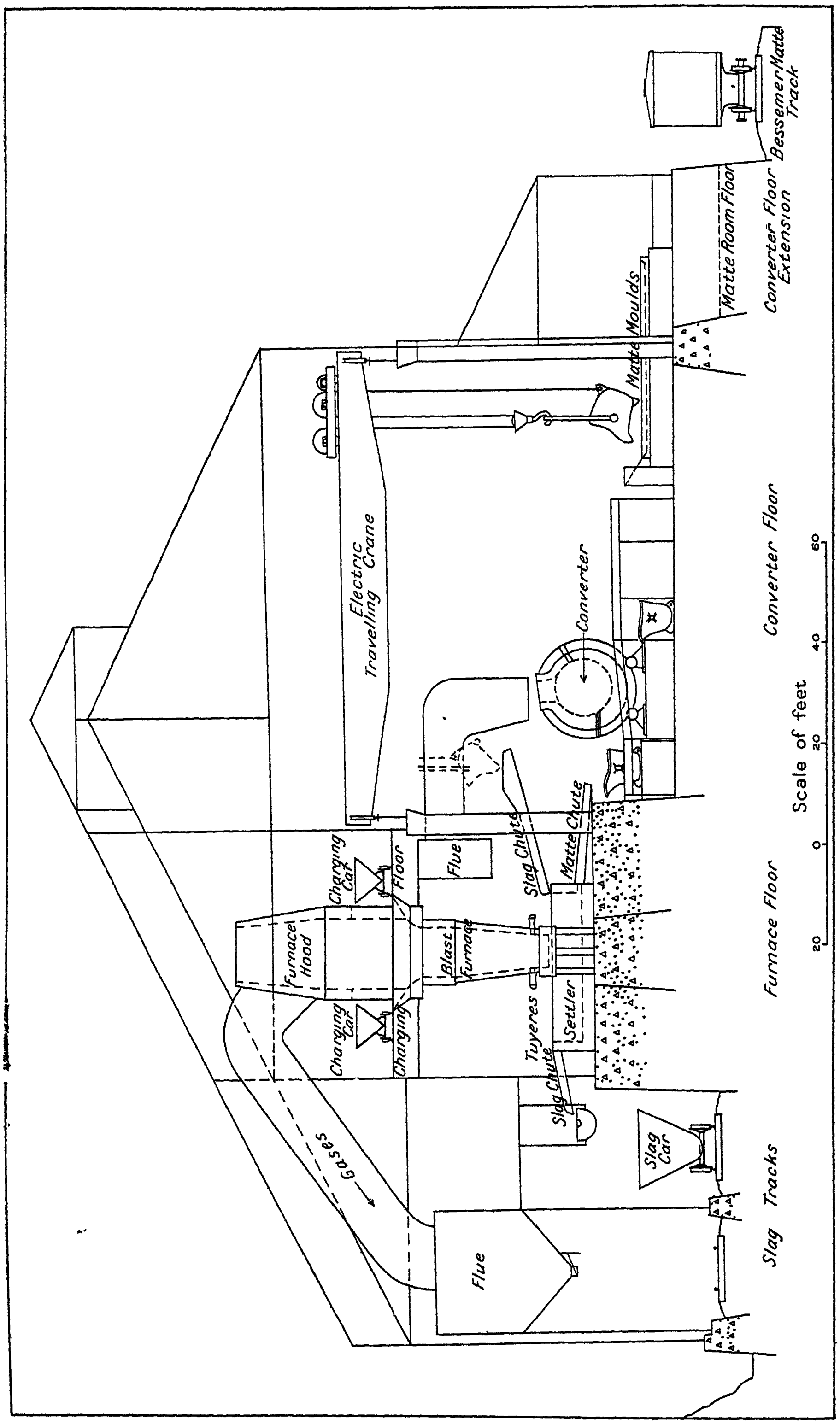


Fig. 80—Cross-section of Coniston Smelter, Mond Nickel Company, Ontario.

and taken to the moulds; the output per 24 hours is 50 to 60 tons, and the composition is shown in the table given above.

The slag from the converters is run into the blast furnace settlers, where any suspended globules of matte settle out.

Power

Electric power for the operation of the mines and smelter of the Mond Nickel Company is bought in part from the Wahnipitae Power Company, and the balance is generated at the company's own plants at Wabageshik and Nairn. Full particulars are given in that part of Chapter IV dealing with Mining Methods.

New Caledonia Ore

The methods of smelting these ores, whether carried on in New Caledonia or elsewhere, have been very little changed since Levat's[1] first description.

The first process tried consisted in reduction of the ore in a blast furnace to a crude ferro-nickel, containing about 65 per cent. of nickel and also 1.5 to 2.5 per cent. of sulphur which came from the fuel; but the refining of this was not successful owing to the impossibility of removing the sulphur, and the present system of smelting to matte was adopted.

The smelting is done in small water-jacketed furnaces, some of which treat 25 to 30 tons of ore per 24 hours. The charge consists of ore, limestone, gypsum and coal or coke, ground together and briquetted, with coke as fuel. The total consumption of coke is about 30 per cent. of the weight of the ore.[2]

Average analyses of the ore and furnace products, as stated by Levat in 1892, are given below:—

——	Ni	Fe.	S.	SiO_2	Al_2O_3	MgO.	H_2O.
Ore	7 to 8	14 to 16	....	45 to 50	3 to 5	10 to 12	14 to 16
Matte	50 to 55	25 to 30	16 to 18	....	....	....	....
Slag	0.40 to 0.45	12 to 13	....	48	....	....	....

When describing the smelting for crude matte, Levat remarks "the local smelting was given up owing to the difficulties in procuring coke, and now the ores are for the most part smelted in England, alkali waste being used as flux."

That local smelting has been resumed and shows a considerable development, is indicated by the following statistics in metric tons (2,204 lbs.) of ore and matte shipped from New Caledonia:—

Year	Ore	Matte
1911	142,000	2,993
1912	74,314	5,098
1913	93,190	5,893
1914	94,154	5,277
1915	48,576	5,529

[1] Annales des Mines, 1892, quoted in the Report of the Ontario Bureau of Mines for 1892, pages 149 to 152. See also A. G. Charleton, J. Soc. Arts, Vol. 42, 1894, p. 496 to 512, and Vol. 43, 1895, p 609 to 661.

[2] Notes on Smelting are also given in the section of Chapter IV dealing with New Caledonia.

The ore is said to have averaged 6.25 per cent. in 1913, and the matte 43 to 45 per cent. nickel. Rather over 30 per cent. of the nickel produced in the island in 1913 was exported in the form of matte but, owing to the preferential treatment of the matte as regards taxes and for other reasons, this proportion of matte is rapidly growing.

Further Treatment of the Matte

The next step in the treatment of New Caledonian 40 to 45 per cent. matte consists merely in the removal of sulphur and iron, followed by the reduction to metal of the nickel oxide so produced. These operations can hardly be termed refining, and the following description has therefore been included under the present Chapter, to save a cross reference to the one on Refining Processes.

The crude furnace matte from New Caledonia is shipped, as is stated in greater detail in the introduction to this Chapter, to Havre (France), Iserlohn (Westphalia, Germany), Antwerp (Belgium), Kirkintilloch (Scotland), and New Jersey, U.S.A. At each of these points it is de-ferrated or bessemerized in small sized converters with the usual silicious flux. The product, which contains 70 to 80 per cent. of nickel, about 22 per cent. of sulphur and commonly only 0.25 per cent. of iron, may be taken as equivalent to the ordinary 80 per cent. bessemer matte from the Canadian smelters, except that it contains no copper.

A little crude ferro-nickel and a considerable amount of ore from New Caledonia, is also shipped to Havre and Kirkintilloch, at each of which the blast furnace and converter operations are carried on. From these two points, the de-ferrated matte is sent to Erdington near Birmingham, England, or Hafod Isha, Wales, for reduction to metal.

At each plant, the matte is crushed to 60-mesh in ball mills and roasted "sweet." At Erdington, two sets of ordinary reverberatory coal-fired, hand-rabbled furnaces, each with one firebox and 5 hearths, are employed while, at Hafod Isha, there are 9 single hearth calciners. The reduction process, as adopted at Erdington, is as follows, and is identical in principle with that at Hafod Isha and elsewhere for the production of rondelles or cubes.

The roast starts at a low red heat and finishes at bright redness, giving a product practically free from sulphur, which is ground and mixed with some farinaceous material, which serves both as a binder and as a reducing agent. The mass is briquetted into circular discs called "rondelles," which are about 2 in. in diameter and 1½ in. thick, and weigh, approximately, 12 ounces. A small proportion is also moulded into cubes about ¾ in. in diameter, or cut into cubes from a flat cake. These two forms are merely adopted to suit the requirements or prejudices of the users. The rondelles or cubes after drying in ovens, are charged with charcoal in alternating layers, into horizontal retorts, which are heated to bright redness. Although reduction is practically complete in 24 hours, it is considered safer to continue the heating for double that period. The metal with the unburnt charcoal, is drawn into hot iron bins, cooled, and screened; the rondelles, after polishing by tumbling in a drum, are ready for the market. They assay 99.25 per cent. nickel and are sold mainly to the makers of nickel steel, nickel silver, cupro-nickel, etc.

The works at Havre, Iserlohn, Kirkintilloch and Erdington belong to the Société Anonyme le Nickel of New Caledonia, the first named being utilized to

supply their French customers and certain other European demands, the second for a portion of the German requirements, and the two last for the British steel and white metal industries. The Hafod Isha works belongs to the Anglo-French Nickel Co., Ltd., which has a working agreement with Le Nickel, from whom they obtain their supplies of matte, but whose shareholders are mainly the large steel producers of Great Britain. The company, in fact, uses the whole of its produce, and is not usually in the market as a seller of nickel.

The Erdington works is a small, old established plant near Birmingham, and was formerly engaged in the manufacture of various nickel silver, cupro-nickel and other alloys for the local trade. It now makes the metal only, and sells it mainly in the district to the makers of nickel alloys.

The Kirkintilloch works smelts raw New Caledonian ore and crude New Caledonian matte, as well as a certain quantity of ore purchased elsewhere. Its bessemerized matte is distributed to those who produce the metal, including the works at Erdington and Hafod Isha.

The output of metal from New Caledonian ore, from these three works in Great Britain, is at least as great as that obtained there from Canadian matte.

The Hafod Isha works, for instance, has an annual output of 3,500 to 4,000 long tons of nickel and employs 300 hands. It is supplied with bag houses and other up-to-date contrivances for preventing loss of dust, etc., and a bessemer converter, so that the company can treat low grade matte, although at present it never receives anything except the de-ferrated matte, which requires only roasting and reduction with carbon, to produce nickel fully up to market requirements for both steel and ordinary white metal.

Norwegian Ore

Although Norway was among the earliest sources of nickel ore for export, it is only since about 1870 that actual smelting operations have been carried on in that country, and only during the last ten years can the complete smelting and refining industry be considered to have been actually established.

The evidence of Mr. V. N. Hybinette and of Mr. F. L. Merry, printed in the Appendix, contains much matter of historical interest in connection with the early work in Sweden and Norway, that of the former being of especial interest as it outlines his connection with and gives information regarding early work in the United States on Sudbury matte.

The principal mines which furnish the Norwegian ore are the Senjen, Evje, Ringerike, Dambler and Kragero. The Dambler is a recently-opened mine operated by Johan Dahl, and has a smelter. The others furnish the supply to the A/S Kristianssands Nikkelraffineringsverk, whose smelters are at Evje, Ringerike and Stavanger, with a central refinery at Kristianssands.

Before the war this company smelted with its own ore, a considerable quantity from Greece, Tasmania and New Caledonia, together with some matte from the last named. Since the war began, only Norwegian ore has been smelted, and it is interesting and important to note, that in 1915 Norway exported no less than 409.9 tons (of 2,000 lbs.) of matte containing 265 tons, i.e., 64 6 per cent., of nickel, to the United States, as compared with under 3½ tons in 1914, and practically none before or since.

The average nickel content of the ore is but little over 1 per cent., and the actual final recoveries are stated to amount to about 1.0 per cent. of nickel and 0.7 per cent. of copper, and about 4 grammes (i.e., about ⅛ oz. Troy) of the precious metals per ton (of 2,204 lbs.) of ore. The value of the precious metal contents is not accurately known, but their recovery adds considerably to the profits and the actual amount recovered appears to represent not less than 50 cents per ton of ore smelted. About 95 per cent. of the total precious metal contents of the ore is said to be silver, palladium coming next in amount, then platinum and finally gold.

In 1914, the Ringerike mine, situated in Hole, Buskerud county (opened in 1900) produced 19,945 metric tons of ore and employed 86 work people in the mine and smeltery; the Flaadt mine in Evje, Nedenes county (opened in 1869) produced 27,909 tons and employed 110 work people. In addition about 2,000 tons of ore from the Faeo mine, 2,000 tons of ore purchased from Greece, and a smaller amount from other places abroad, was smelted at Evje.

It is interesting to note that the number of hands employed at the Kristianssands refinery amounts only to about 100, so that in Norway, as is the case with the Sudbury ore, the principal expenditure on labour is in mining and smelting.

The head office of the company, at Kristiania, has kindly furnished the Commission with the following particulars relating mainly to mining and smelting, but including also certain figures concerning the refining, which will be found repeated in the Chapter dealing with Refining:—

Approximate Costs Under Pre-War Conditions

Labour.	Kroners.[1]	Per
In the mine	7.00	8 hours shift.
On the surface	5.00	10 " "
In the smelter	5.00	8 " "
General.		
Coke	30.00	ton.
Sulphuric acid	5.40	100 kilos f.o.b Amsterdam.
Coal	20.00	ton.
Wood	15.00	cu. met.
Current	50 00	H P.

Voltage at which current is received—25,000 volts.

Analyses

——	Ni.	Cu	Fe	S	As	Co
Ore	1.60	0.90	....	....	....	....
Bessemer Matte	47.00	32.00	0 18	....	....	....
Refined Nickel	98.75	0.10	0.50	0.01	....	....
" Copper	0.14	99.72	0.022	0.0103	0.0038	0.008

The refined copper carries about 0.10 per cent. graphite on the surface where stripped from the cathode.

[1] One kroner may be taken as 27 cents.

The Commission was also furnished at the company's office in Kristiania with a considerable amount of confidential information as to smelting and refining costs, recoveries, etc., in addition to the following, which they received permission to publish:—

Ore Smelted at Evje in 1914

	Metric tons
From Flaadt mine	30,170
From Faeo mine	1,091
Grecian ore (purchased)	850
Australian ore (purchased)	2,802
	34,913

The yield was 1287.5 tons of matte containing 645.93 tons of nickel and 350.88 tons of copper.

In the last two years for which figures are available, the quantities of nickel and copper sold were:—

	1914. Tons.	1915 Tons.
Nickel	695.7	817 2
Copper	370.0	415.9

The output of the Nikkelraffineringsverk goes to Germany.

The smelting operations at Evje and Ringerike and at the small works owned by the company at Stavanger, are practically identical, and do not differ in principle from those in use in Sudbury, although carried out on a much smaller scale.

According to information supplied at Kristianssands, the Evje ore has a highly basic gangue and contains only about 10 per cent. of sulphur. No heap roasting is carried out, and even smelting is given up during the summer months (June to August) on account of injury to the trees in the district.

The blast furnaces in use are small, and are not water-jacketed in the ordinary sense of the word, although the lower part of the brickwork contains water-cooled pipes. No roasting plant is used, and there are no reverberatory furnaces.

The blast furnace matte contains only about 10 per cent. of nickel plus copper and 40 per cent. of sulphur, the remainder being mainly iron. It is bessemerized in small basic converters of the Pierce-Smith type, identical in principle with those in use in Sudbury, but of much smaller capacity.

The bessemerized matte contains about 80 per cent. of nickel plus copper (commonly 47 per cent. of nickel and 32 to 34 per cent. of copper) with about 20 per cent. of sulphur, and from under 0.25 to about 0.4 per cent. of iron.

The cost of mining at Evje is stated to have been 7 kr. in 1914 and 9 kr. in 1915 per metric ton, of ore delivered at the smelter, and 10 kr. in 1914 and 11 kr. in 1915 for smelting and bessemerizing, i.e., a total of 17 and 20 kr. respectively per ton of final matte, apart from the value of the ore.

CHAPTER IX

Refining Processes

Introduction

There are three processes which can be described as standard methods, in use for the refining of nickel. These are (1) the Orford process, (2) the Mond process, and (3) the electrolytic process or processes. The production of a matte is essential for each, and the same method of matte production is employed for all three. Even the matte from New Caledonian ore, although obtained by a different method, is similar in composition to that produced at Sudbury, except for the absence of copper. The methods employed are described in detail later in this Chapter.

The Orford process, which consists mainly of a series of furnace treatments, is cheap in operation, but is burdened by losses in slag, and by lack of sharpness in effecting the separation of the metals present in the matte. The progressive enrichment in nickel attained by the repeated smeltings, also appears to result in greater losses of both nickel and copper than the other processes, and the small proportion of the precious metals which it recovers is a serious and permanent handicap.

The Mond process may be regarded more as a matter of chemical engineering. The whole work is carried out automatically and continuously with a minimum of labour, and with a resultant economy which largely offsets the greater capital cost, and the higher skill required of the operators. The losses of nickel and copper in this process are very small, and the recovery of the precious metals very complete.

Similarly, the electrolytic processes, while not necessarily cheap, have the advantages of elasticity, facility with which plant can be enlarged, purity of products, ease of producing metals of whatever purity different market requirements may demand, small losses, and an almost complete recovery of the precious metals.

Among other processes which have been suggested, that of McKechnie and Beasley[1] may be referred to, as the inventors have sent to the Commission particulars of certain trials made by them. A description of the process is given in the specifications, and the inventors state that the results on the Sudbury copper-nickel matte have been promising. Briefly stated, the invention consists in treating the partly roasted or raw matte with sulphuric acid under pressure in a lead-lined vessel. The nickel is dissolved as sulphate, and can be recovered by electrolysis or otherwise, or crystallized out. The copper remains as the insoluble sulphide with the precious metals. In other words, the sulphuretted hydrogen produced by the reaction is utilized as a precipitant for the copper.

[1] Alexander McKechnie and Frederic Beasley, British patent No. 15,850, July 8, 1911, and Canadian patent No. 143,074, October, 1912

No. 1

No. 2

No. 3

No. 4

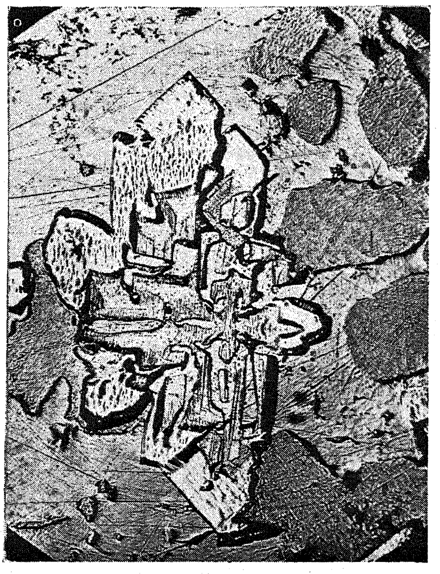
Photomicrographs by Wm. Campbell of polished surfaces of converter matte from Copper Cliff, Ontario, showing character of matte. This matte contains approximately 23.5 per cent. of copper and 55.4 per cent, of nickel. Magnified about 70 diameters.

No. 1, etched with ferric chloride solution; deeply etched crystals are metal; i.e., copper-nickel solid solution (containing some sulphur). In relief are rounded, irregular patches of blue Cu_2S in a matrix of yellow Ni_3S_2. The Ni_3S_2 in the centre of the photomicrograph is full of small dots and threads of Cu_2S—this is the eutectic of Ni_3S_2 and Cu_2S.

No. 2, etched with ferric chloride solution; deeply etched crystals are metal, as in No. 1, intergrown with Cu_2S. Crystal centres are not of same composition as outside. Matrix:—grains of Cu_2S in groundmass of Ni_3S_2.

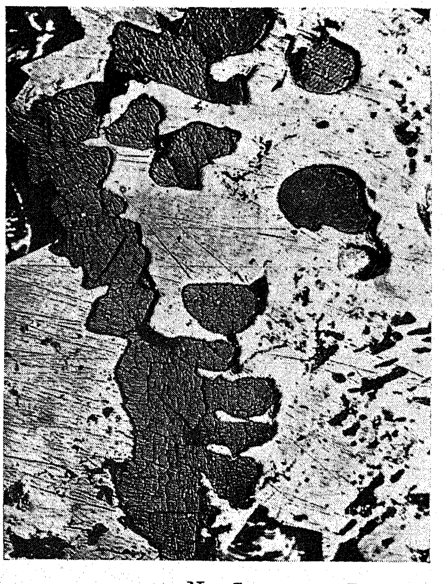
No. 3, intergrowth of metal and Cu_2S. Matrix of Ni_3S_2.

No. 4, eutectics of Cu_2S and Ni_3S_2, and of metal and Cu_2S and Ni_3S_2 (ternary eutectic?).



No. 5

No. 6



No. 7

No. 8

Photomicrographs by Wm. Campbell of polished surfaces of converter matte from Copper Cliff, Ontario, showing character of matte. This matte contains approximately 23.5 per cent. of copper and 55.4 per cent. of nickel. Magnified about 170 diameters.

No. 5, crystal of metal; i.e., copper-nickel solid solution, showing a core of different composition, containing inclusions of Ni_3S_2. Grey globules are Cu_2S. Matrix is Ni_3S_2.

No. 6, coarse grains and globules of Cu_2S. Matrix of metal as crystals (black), and Ni_3S_2.

No. 7, etched with HNO_3, 1 to 1. Cu_2S shows cleavage.

No. 8, eutectic of Cu_2S (dark) and Ni_3S_2 (light).

Nickel Matte

Although the metallurgical use of the term "matte" includes all metallic sub-sulphides obtained by furnace smelting, and nickel matte includes the ordinary blast furnace and reverberatory furnace mattes produced by the smelting of raw or partly oxidized nickel sulphide ores, it is usual to take "nickel matte" to mean rich bessemerized matte containing about 80 per cent. of metal, i.e., either the nickel-copper matte made in Ontario, or the true nickel matte made from New Caledonian and other oxidized ores, by smelting with the aid of sulphur-containing materials. It is usual in Canada, in fact, to use the terms matte, bessemer matte and converter matte as synonymous.

Such matte is practically free from iron, of which it usually contains under one-half of one per cent. The bessemerized matte made from New Caledonian ore contains from 65 to 75 per cent. of nickel, the balance being sulphur. Although it is possible to bessemerize such matte to 80 per cent. or even more of nickel, the losses are heavy, and as the bulk of it is mainly roasted to oxide and reduced direct to metal with carbon, there is no advantage in carrying the bessemerizing beyond 70 or 75 per cent., provided the bulk of the iron has been removed. In the case of the Sudbury matte, the presence of a considerable amount of copper permits the carrying of the bessemerizing to a much greater limit without excessive loss, and well beyond 80 per cent. of nickel plus copper is sometimes obtained. Different blows vary considerably, from rarely as low as 75 per cent. of nickel plus copper, to rarely as high as 85 per cent. The aim in bessemerizing nickel matte may be taken to average about 80 per cent. of nickel plus copper and under one-half of one per cent. of iron, the balance of about 20 per cent. being sulphur. This is the case whether the matte is intended to be refined by the Orford, the Mond, or the electrolytic process.

Although the relative proportions of nickel and copper in the finished matte vary greatly, and depend entirely on the composition of the original ore, the close adherence to the 80 per cent. standard, even from the birth of the bessemerizing of the nickel matte in Swansea, has been surprising. In the case of the Canadian Copper Company, the matte in 1907 averaged 78.79 per cent. of the mixed metals, and from then until 1916, when the output was over three times that of 1907, and the matte averaged 78.51 per cent., it never rose above 80.5 or fell below 78.5 per cent. The amount of nickel in the Canadian Copper Company's matte has varied from 46.78 per cent. in 1908, to 56.31 per cent. in 1913. During the last three years, it has not fallen below 53.5 or risen above 53.89 per cent. Similarly, the copper in 1908 was 33.29 per cent., and has never risen beyond that amount or fallen below 22.7 per cent., the last three years showing a maximum of 29.94 in 1914, and a minimum of 24.99 in 1916.

The methods used for the manufacture of nickel matte by the several companies have been fully described, the plant illustrated, the assays given, and the losses incurred in its production and its general nature and composition, dealt with and discussed in Chapter VIII on Smelting Nickel Ores.

From Matte to Metal

The term "refining" is commonly employed in metallurgy to designate the final stages during which a crude metal is raised from say about 95 per cent. to ordinary pure metal. In this Chapter, however, the word refining is taken to cover the methods of producing nickel of good commercial quality from bessemer matte, as that may be taken as the common meaning given to the term in the nickel industry, and invariably meant when considering that of Ontario.

Were it not for the comparatively small quantity of nickel produced in Norway from pyrrhotite ore, and that obtained as a by-product in the electrolytic refining of copper, it might be stated that all nickel is exported as matte from the country of origin, e.g., Canada or New Caledonia, to Great Britain, France and the United States. It is true that the New Caledonian product is a lower grade blast furnace matte, but the first step in its treatment after arrival in Europe is a bessemerizing or de-ferrating operation, which produces an 80 per cent. matte. In this respect, the nickel and copper industries are very similar, as it is more common for the crude copper produced at the smelter to be shipped to a distant refinery than to be converted into marketable metal where produced.

For the above reasons, it is usual and right to regard the bessemerized matte as a definite line of demarcation between smelting and refining. It completes the former, and may conveniently be regarded as the starting point for the refining. On its assay and yield of precious metals, are based the refining charges and the share of the total costs which the smelting and refining should bear.

Losses in Smelting and Refining

The assay of the bessemerized matte shows the losses which have been incurred from the mine to the completion of the smelting, although it is extremely difficult to absolutely determine such losses, on account of the impossibility of accurately assaying all the supplies which pass to and through the smelter. The refining losses, however, are accurately known to the operators and, except in the case of the refining by the International Nickel Company, to the Commission.

It has not been considered necessary or advisable to publish these losses, partly because of their confidential nature, but largely on account of the fact that they would be extremely deceptive. It is not possible, for instance, to compare the losses incurred in refining a matte containing 54 per cent. of nickel and about 25 per cent. of copper such as is produced by the Canadian Copper Company and refined by the Orford process, which produces metallic nickel, metallic copper, nickel sulphate and Monel metal, but only recovers a small proportion of the precious metals, with those on a matte containing 40 to 41 per cent. each of nickel and copper like that produced by the Mond Company, and refined by its special process, in which no metallic copper is produced. A considerable proportion of the nickel is obtained by the Mond Company and sold as nickel sulphate, the whole of the copper is sold as copper sulphate, and practically the whole of the precious metals are recovered and sold in a crude form. The difficulty of allocating costs or profits between mining, smelting and refining, is enhanced by the fact that the two companies have very different values in the ores which they smelt,

so that the cost for refining per ton of matte gives scarcely any idea as to the relative profits of the different companies per ton of ore.

Matte Costs and Values

Mining and smelting costs have been supplied by each of the different companies, and the costs of refining from bessemerized matte have been furnished by the Mond Nickel Company and the Nikkelraffineringsverk of Kristianssands in Norway, whose process will form the basis of that to be adopted by the British America Nickel Corporation. The International Nickel Company have not supplied particulars as to their refining costs.

As already stated, it is impossible to fix any actual value for either ore or matte. The former is seldom sold, as it is usually mined by those who smelt it, but when sold, the price is based on its nickel and copper values only, without regard to its fluxing value in admixture with other ores. Such is the case, for instance, with the ore from the Alexo mine, which is sold to the Mond Nickel Company on a definite basis for its nickel and copper contents only, the amount at present mined being too small to justify the erection of a smelter at the mine for effecting a preliminary concentration as blast furnace matte.

The bessemerized matte sent to the refineries is valued on an arbitrary basis for convenience of accountancy. The figures taken by the Canadian Copper Company are 10 cents per pound for nickel contents, and 7 cents per pound for copper. This figure is the one which has been used between the Canadian Copper Company and the International Nickel Company since the year ending March 31, 1909. The Mond Nickel Company takes the nickel at 15 cents and the copper at 7½ cents. Both companies, however, merely use these simple arbitrary figures for conveniences of calculation. The figure agreed upon between the Canadian Copper Company and International Nickel Company is used by the United States statisticians in calculating out the value of the matte imported from Canada, the usual practice, when an article is duty free, being to take the value placed upon the goods by the importer. The money equivalent of the assay value of the metal contents is practically never published in the case of nickel or nickel-copper mattes, i.e., a valuation based upon the market price of the metals themselves, and this is probably wise, on account of the number of metals involved if one includes the precious metals, as is necessary if a definite money value is to be stated.

In the Preliminary Report on the Mineral Production of Canada for 1915, Department of Mines, Ottawa, page 12, the exports of nickel are stated to be reported by the Customs Department, at an average of 11.13 cents per pound. This would no doubt be based on the relative quantities of matte exported by the Canadian Copper Company and the Mond Nickel Company, and on the valuation placed on them by those companies. On the same page, the Report states that the exports of metallic nickel from the United States during the 11 months ending November, were valued at an average of 37.97 cents, and that the value of the United States exports in 1914 ranged from 31 to 39 cents, and averaged about 34 cents. The quotations during the first seven months of the year varied between 40 and 45 cents per pound for ordinary nickel, with an additional 5

cents per pound for electrolytic nickel. The price during the last 5 months of the year is stated to have ranged between 45 and 50 cents for ordinary nickel, but the quotations given in trade journals for nickel are of doubtful value. Until 1915, the Bureau of Mines of Ontario valued the matte on the same basis as was used by the producers, i.e., by the Canadian Copper Company and the Mond Nickel Company but in 1915 it definitely adopted for that year a basis of 25 cents per pound for the nickel and 10 cents per pound for the copper, increased in 1916 to 18½ cents for the latter.

By-product Nickel

It is a mistake to suppose that all the nickel produced in the world comes from nickel ores worked as such. This is by no means the case, and a considerable and apparently increasing quantity is derived from sources not usually regarded as yielding the metal. In addition to the production in Ontario of nickel oxide and metallic nickel from the ores of the Cobalt district as a by-product from cobalt refining, a highly important source, particularly in the United States, is the blister copper, of which about a million tons per annum are there now refined.

The copper from some districts is much richer in nickel than from others, but it may be stated as a fact, that there is no large quantity of blister copper refined which does not yield a certain proportion of nickel. The ore from the Katanga district in South Africa is exceptionally rich, and large quantities of blister copper, stated to contain about 3 per cent. of cobalt and nickel, are said to have been sent prior to the war to Germany, where the cobalt and nickel and also the precious metals were extracted. One estimate indicates that Germany obtained about 800 tons of nickel and cobalt in a single year from ore from this source. Similarly, the Kuhara Mining Company, Limited, of Japan, obtains considerable quantities of nickel in refining blister copper obtained from the Hitachi mine owned by the company and from imported ore.

The most important source of by-product nickel however, is the electrolysis or electrolytic refining of blister copper in the United States. There are, in the vicinity of New York, nine large refineries which in 1914 had a total capacity of 1,778,000,000 lbs. of copper, the smallest having a capacity of about 48,000,000 lbs., and the largest about 400,000,000 lbs. The refining facilities in this locality have since been largely increased. One refinery, that of the American Smelting and Refining Company, Perth Amboy, New Jersey, having a capacity of over 200,000,000 lbs., is stated to obtain about 50 tons of metallic nickel monthly from the refining of the blister copper obtained by them from various sources. The Mineral Resources of the United States for 1914[1] states that 845,333 lbs. of metallic nickel, valued at $313,000, were thus obtained in the States in 1914. The following table quoted from Eilers[2] with additions from the above quoted Mineral Resources and from Charles H. Fulton's bulletin on The Buying and Selling of Ores and Metallurgical Products,[3] gives the following recovery of various metals, as by-products from the refining of 100 tons of blister copper; the amount of nickel is shown in the last column:—

[1] Part 1, p. 927.
[2] Trans. Am. Inst. Mg. Eng., 1914, Vol. 47, pp. 217-18
[3] U. S. Bur. Min. Technical Paper No. 83.

No.	Refinery.	Gold.	Silver.	Platinum.	Palladium.	Nickel.
		oz.	oz.	oz.	oz.	lbs.
1	Garfield, Utah.............	288	3,480	0.342	1.183	40
2	Steptoe, Nev..............	169	550	1.016	4.402	64
3	Omaha, Nebr.	360	23,090	1.825	6.486	944
4	Mountain, Cal..............	1,418	10,990	1.320	0.607	11.5
5	Tacoma, Wash	2,187	8,710	0.710	3.327	770
6	Aguascalientes	482	67,300	0.416	0.226	12
7	Cerro de Pasco	170	9,900	0.319	0.589	32
8	Mount Lyell...............	464.5	7,205	0.624	1.374	166
9	Anaconda, Mont.	....	....	....	....	22
10	Great Falls, Montana	....	....	....	....	68

Although it is impossible to say how much nickel is actually present in the total blister copper treated, it is safe to estimate a recoverable amount of over one pound of nickel for every ton of blister copper now refined or likely to be refined in the future. From the blister copper obtained in the United States from ore produced in that country, at least 500 tons of metallic nickel is now produced annually, and over half as much more is obtained from ores received from abroad, including a considerable quantity from the blister copper sold by the International Nickel Company. In view of the tremendous production of copper which has been going on in the United States during the last two years or more, this estimate is almost certainly too low. There is also an unknown quantity recovered from the treatment of waste metals containing nickel. The primary source of such waste or secondary metals is, of course, unknown, but the amount of nickel which is thus returned into circulation every year, either as ordinary pure nickel or in the form of alloys, is considerable, and is probably more than that obtained by the refining of blister copper. A certain proportion of the precious metals shown in the table, is also produced from such nickel-copper ore. It is, however, interesting to note that, although the ten companies referred to produce so much nickel, they are practically occupied only in the refining of ores from properties none of which are operated as an actual source of nickel. It may be mentioned that the capacity of the Anaconda Copper Mining Co., of Great Falls, Montana, is 65,000,000 lbs. of copper, and that of the Tacoma Smelting Company is 48,000,000 lbs.

In connection with the recovery of nickel from the electrolytic refining of blister copper in the United States, the most recent particulars are given in a pamphlet by Frank L. Hess, entitled Nickel in 1915.[1]

No direct production of nickel from American nickel ores is known to have been made in this country since 1909, when the American Lead Co. operated a smelter at Fredericktown, Mo, for a short period.

In the electrolytic refining of copper the nickel, which is found in small quantity in practically all blister or other copper that has not been previously electrolytically refined, goes into solution in the electrolyte. The electrolyte must be watched in order that not more than 1 per cent. of nickel shall accumulate, for excess of this quantity is said to interfere with the smooth deposition of the copper, and thus to cause short circuiting and other troubles.

From the electrolytes the nickel is saved as nickel sulphate. Formerly a large quantity of nickel ammonium sulphate was also made, but none is now reported. The other companies sell the nickel sulphate, which is used for nickel plating, but the American Smelting and Refining Co. reduces the salts saved in its refineries, to metal.

[1] U. S. Geol. Sur., 12th January, 1917.

The first production of by-product nickel in the electrolytic refining of copper known to have been made in this country was made in 1908. During the last five years the saving has been as follows:

Nickel content of salts and metallic nickel produced as by-product in electrolytic refining of copper, 1911-1915.

Year	Quantity (short tons)	Value
1911	445	$127,000
1912	328	93,600
1913	241	79,393
1914	423	313,000
1915	822	538,222

The Orford Process

This is the oldest method in use for the refining of nickel-copper matte, and is based on methods employed in England before the Sudbury ores were exploited.

The Commission has not been furnished with particulars as to the process at present in use at Bayonne, N.J., where the Orford process is employed, but much statistical information has been furnished by the International Nickel Company, and one member of the Commission was shown over the works.

Practically nothing has been published as to the consecutive steps in the process, which, although simple in principle, involves a large variety of detail operations, but the accompanying flow-sheet (Fig. 81) published by Titus Ulke[1], gives a fair idea of the general lines of treatment, although somewhat out of date.

The Orford process is cheap to operate, and permits of a very large output in a confined space, but it does not recover more than a small proportion of the precious metals, and there is reason to think that the losses of nickel and copper are heavier than in either of the other processes. The losses in refining are not known to the Commission, but the amount of precious metals sold by the International Nickel Company is small compared with the total known to be contained in the matte received by them. The nickel which they sell as such, contains both platinum and palladium, and the Monel metal, of which they sell large quantities, also contains those metals, in addition to gold and silver.

The process depends upon the fact that if a matte consisting of the sulphides of iron, copper and nickel be fused with sodium sulphide or with sodium sulphate and coal (which mixture produces sodium sulphide on fusion), the product separates into two layers. Of these, the upper and more fusible is composed of double sulphides of sodium and copper and of sodium and iron, with a small proportion of nickel, and is often called a matte, although better described as a slag. The greater part of the nickel sulphide, with small quantities of copper and iron, forms a matte which sinks to the bottom. These two products are known as "tops" and "bottoms," and a fairly complete concentration of the nickel in the "bottoms" and of the copper in the "tops" may be effected by repetitions of the operation.

For a number of years, this separation was effected by smelting the bessemer matte from Sudbury with coke and sodium sulphate in a cupola furnace, and tapping into pots, the layers being broken apart when cold. So much iron and copper remained with the nickel in the bottoms however, that it was necessary

[1] See Eng. and Min. J., January 30, 1897, p. 113, and July 3, 1897, p. 8.

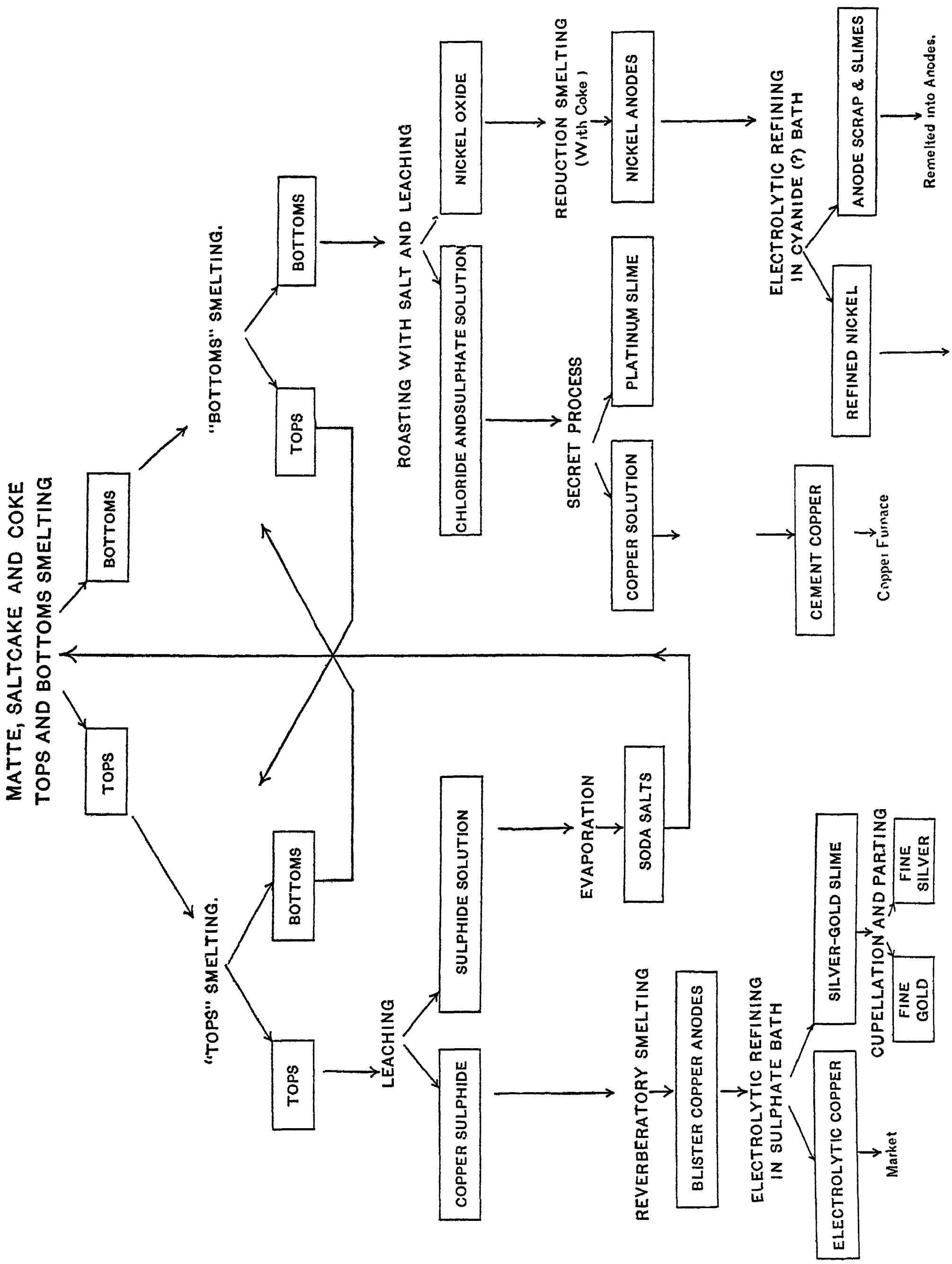


Fig. 81—Flow-sheet, Orford Refining Process.

to repeat the fusion four or five times until the former metals were reduced to so low a proportion as to permit the production of fairly pure nickel by roasting the nickel matte and reducing it with carbon.

Thompson and Monell Patents

Although old in principle and used in Wales before the Sudbury deposits were discovered, the process has formed the subject of several patents in the United States, among which mention may be made of those of R. M. Thompson, Jan. 10, 1893, Nos. 498,574, 498,573, and 498,576; and of C. C. Bartlett, June 13, 1893, No. 499,314. The last-named formed the basis of the patent of Ambrose Monell, Oct. 17, 1905, No. 802,012, from whose specification the following is quoted:—

Instead of smelting the compound matte, as heretofore, in a cupola-furnace and running the product continuously into molds I so smelt the matte that when melted it will remain in a molten state subject to the high temperature of a furnace for a considerable period of time, during which I find that the copper and iron sulfids will be thoroughly dissolved by the sodium sulfid, and in one melting a good separation can be effected, and by two such treatments results are obtained equal or superior to the results of the four or five meltings which have been employed heretofore. For this purpose I employ as the smelting-furnace an open-hearth reverberatory furnace lined with magnesite brick, as I find that silica-lined furnaces are quickly destroyed by fluxing with the sodium sulfid. Into such furnaces I introduce a charge of nickel-copper-iron matte, either solid or molten, together with coke and sodium sulfate, the latter being preferably present in the proportion of sixty per cent. of the weight of the matte, and the coke in the proportion of fifteen per cent. of the matte. The sulfate is preferably added in the form of commercial niter-cake. Where, for example, a fifty-ton charge of matte is treated containing, say, forty-five per cent. of nickel sulfid and thirty-five per cent. of copper sulfid, it is melted in the furnace and retained subject to the heat for some time—say, four to five hours after fusion has occurred—during which time it is preferably "poled"—that is to say, treated by immersing beneath its surface poles of green wood, which evolve hydrocarbon gases and vapors, and thus aid in the reduction of the sulfate and produce an agitation of the material, which facilitates and renders more thorough the solution of the sulfids to be removed. Nearly complete solution of the copper and iron sulfids in the sodium sulfid reduced from the niter-cake is thus effected, and the molten charge may be tapped from the furnace and allowed to separate in molds; but to get the best results I tap the different strata from the furnace separately, tapping first the solution of copper and iron sulfids floating on the surface of the bath and finally tapping the undissolved nickel sulfid, or the order of tapping may be reversed, the lower stratum of nickel sulfid being removed first. The great proportion of the iron and copper is thus separated, the nickel sulfid obtained being nearly pure. Where greater purity is desired, the nickel sulfid may be recharged into the furnace and treated again in like manner.

Operation of Process and Products

In carrying out the process, the final "tops" containing most of the copper and iron originally present in the bessemer matte, are leached, yielding a solution of the various sodium salts which, after evaporation, are returned for the "top and bottom" smelting. The remaining sulphides, which carry the bulk of the gold and silver originally in the matte, are smelted to blister copper containing about 2.5 per cent. nickel, and this is sold to the electrolytic refiners, who recover also the nickel and the precious metals.

The final "bottoms," consisting of a matte very rich in nickel, but still containing a small quantity of copper, are ground and roasted with salt in a reverberatory furnace so as to form a maximum quantity of soluble chloride and sulphate of copper and insoluble nickel oxide. The leaching of this product yields a solution containing most of the copper together with some silver, platinum, palladium and rhodium. The solution is treated by a secret process for recovery

of the precious metals. The copper is next recovered by treatment with hot powdered matte or with scrap iron, the resulting cement copper being worked up in the usual way and sold ultimately as blister copper.

The nickel oxide left by the leaching is reduced to metal in reverberatory furnaces with oil burners, and cast into rectangular plaquettes weighing either 25 or 50 lbs. The metal usually contains about 99 per cent. of nickel, including a little cobalt, and not more copper and iron than is permissible for the ordinary uses of nickel.

The company also produces considerable quantities of electrolytic nickel, and in doing so, recovers platinum, palladium, iridium and rhodium, which in the separation into tops and bottoms, and to a great extent even during the leaching, mainly "follow" the nickel, whereas the silver and the gold almost entirely "follow" the copper and are sold in the blister copper, to the refiners, who recover not only the copper, but also a large amount of nickel, together with the gold and silver, and such proportions of the platinum group of metals as it may contain.

Nickel sulphate and nickel-ammonium sulphate are also obtained by crystallization from the leached solutions. Neither copper sulphate nor nickel oxide is sold, whatever is produced of the former being converted into cement copper, while the latter is reduced to metal.

In addition to refined nickel, Monel metal is produced by carrying on the "top and bottom" smelting to such a stage as removes a sufficiency of the copper, roasting the matte and reducing the mixed oxides so produced, in a reverberatory furnace. The properties of this alloy are discussed in the Chapter on the Non-Ferrous Nickel Alloys.

Products Other than Nickel and Copper

The following table shows the production other than of ordinary nickel and copper during the last three fiscal years, each ending March 31st —

——	1914	1915	1916
Electrolytic nickel	1,072,676 lbs.	914,597 lbs.	2,473,162 lbs.
Monel metal	3,526,345 "	2,910,606 "	3,982,018 "
Nickel sulphate	837,413 "	827,207 "	459,005 "
Nickel ammonium sulphate	1,357,705 "	1,065,777 "	1,163,027 "

During the fiscal year ending March 31, 1916, the recovery of precious metals are reported to the Commission by the company as:—

	Oz. Troy
Gold	3,953
Silver	114,975
Platinum and Palladium	1,093
Other metals of the Platinum group (mainly Rhodium and Iridium)	257

The matte received by the company and probably treated during the year amounted to 56,405 tons. According to the 23'rd Annual Report of the Ontario Bureau of Mines, for 1914, p. 21, the average annual recovery of platinum and palladium during the 6 years from 1907-1912 inclusive was 394 oz. of platinum

and 702 oz. of palladium. The average yearly recoveries during those years of gold and silver (Report on the Mineral Production of Canada during the calendar year 1915, pp. 58 and 59) was 2,612 oz. of gold and 76,542 oz. of silver.

These recoveries would be from a total of 133,888 tons of matte produced during the six years. It must be pointed out that the figures given for matte represent the quantity shipped to the Orford Company, and do not accurately show how much was refined during the same periods, but there is every reason to believe that, over a period of years, the receipts of matte and the quantity refined would be about equal. Assuming this to be the case, the recoveries of metals of the platinum group during the six years would correspond to 0.05 oz. per ton of matte. The "assay value" of the metals at $50 per ounce would be $2.50 per ton of matte. Similarly, the recovery during the calendar year ending March 31, 1916, would be 0.024 oz. per ton of matte, representing an assay value of $1.20 per ton of matte.

The price received for the platinum differs from that obtained for the other platinum metals, but the value of the whole averages more than that for platinum, so that the above figures may be taken as conservative, as regards assay value, although they do not allow for the refining charges. The value of $50 taken above is exactly half the price quoted in February, 1917, for ordinary pure platinum in the United States. This round figure has been taken as a resonable "after war" price, as it is the mean of the figures quoted for platinum in the U. S. Geological Survey report on Platinum and Allied Metals, published Aug. 15, 1916, for 1912 to 1915 inclusive.

The ores from the several mines worked by the Canadian Copper Company vary greatly as regards contents of platinum metals. That of the Vermilion mine is by far the richest and is smelted, bessemerized and refined separately as far as possible. A considerable proportion of the platinum group metals recovered by the International Nickel Company is obtained from this separate refining of this Vermilion matte.

For the reduction of the nickel oxide to metal, it is necessary to avoid the introduction of sulphur and the International Nickel Company's plant is conveniently situated next door to one of the Standard Oil Company's refineries, from which is obtained, per annum, between 8,000,000 and 9,000,000 gallons of specially pure oil, containing under 0.25 per cent. of sulphur, for use in their reverberatory furnaces.

The following shows the number of employees in the refinery at New Jersey and at Copper Cliff, December, 1915:—

	Men.	Per Cent.
Labour at Copper Cliff	2,992	68.6
" refinery	1,366	31.4
Total	4,358	100.0

The company has hitherto, owing to the situation of its refinery, been allowed free discharge into the sea of its waste liquors, and into the air of the sulphurous acid gas escaping from its chimney stacks. The waste liquors amount to about 155,000,000 gallons annually, and contain about 1.61 per cent. of sodium salts, consisting of 1 per cent. sodium sulphate, 0.36 per cent. sodium sulphide and 0.25

per cent. sodium carbonate. These figures would correspond to the following weights per annum:— sodium carbonate, 1,647 tons; sodium sulphate, 6,587 tons; sodium sulphide, 2,371 tons; total, 10,605 tons. About 20,000 tons of sulphur dioxide are discharged from the stacks per annum.

The new refinery which the company is erecting at Port Colborne in Ontario, at a cost of about $4,000,000 and which, it is hoped, will be in operation by the autumn of the present year, 1917, is designed to recover the sodium salts by means of waste heat, and to re-use them in the production of tops and bottoms, but the Commission is not aware whether any steps are in mind for the recovery of the sulphurous acid.

The Mond Process

The quantity of matte produced by the Mond Company is less than one-third of that obtained by the Canadian Copper Company, and is of different composition, because, although it contains about the same aggregate of nickel and copper, the relative proportions of the two are very different. The matte from the Canadian Copper Company averages about 54 per cent. nickel and 25 per cent. copper, whereas that from the Mond Nickel Company is much richer in copper, and averages about 41 per cent. nickel and 41 per cent. copper.

The bessemer matte produced at Coniston, Ontario, is shipped to the refining works of the Mond Company at Clydach, about six miles from Swansea, Wales. The site, which includes 45 acres, was selected for the following reasons: Anthracite for the production of producer gas is mined in the neighbourhood; chemicals can be secured at low prices; suitable skilled labour is readily available; and there is cheap ocean transport for raw materials, and for such of the products as are exported.

The process has formed the subject of a large number of British and foreign patents, including the following principal ones:—

Canada		Great Britain		United States	
Date	No.	Date	No.	Date	No.
1890—		1890—		1891—	
Nov. 18..........	35,428	Aug. 12.......	12,626	June 30.......	455,227
Nov. 18..........	35,429	Dec. 24.......	21,025	June 30.......	455,228
Nov. 18..........	35,427	1891—		June 30.......	455,229
1896—		May 11.......	8,083	June 30.......	455,230
Mar. 16..........	51,672	1895—		1895—	
July 2..........	52,789	Dec. 10.......	23,665	Dec. 10.......	551,221
1899—		Dec. 10.......	23,665a	Dec. 10.......	551,220
Mar. 8.........	62,838	1898—		1898—	
		Jan. 14.......	1,106	July 5.......	606,843

The following description of the process has been compiled from particulars supplied in writing by the Mond Nickel Company, and in interviews held by the Commissioners with the company and its directors and other officials, and from a paper read by Sir William Roberts-Austen before the Institution of Civil Engineers, London.[1]

[1] Proc Inst. C. E., 1898-9, Vol. 135. See also 8th Annual Report, Ontario Bureau of Mines, 1899, pp. 106-120.

Although written in the early days of the company, Roberts-Austen's account may still be taken as correctly describing the principle of the process, and, except for unimportant details, the manner in which it is carried out at the present time.

The origin of this important refining process lies in an observation made in 1889 by the late Dr. Ludwig Mond and Dr. Carl Langer in the course of a scientific investigation made in conjunction with Frederick Quincke. Based upon previous experiments, a mixture of carbon monoxide and hydrogen was passed over finely divided nickel at 350° C. with the object of removing the carbon monoxide; and to obviate any possible danger from escape of the latter poisonous compound, the escaping gas was ignited. It was observed that, as the apparatus cooled

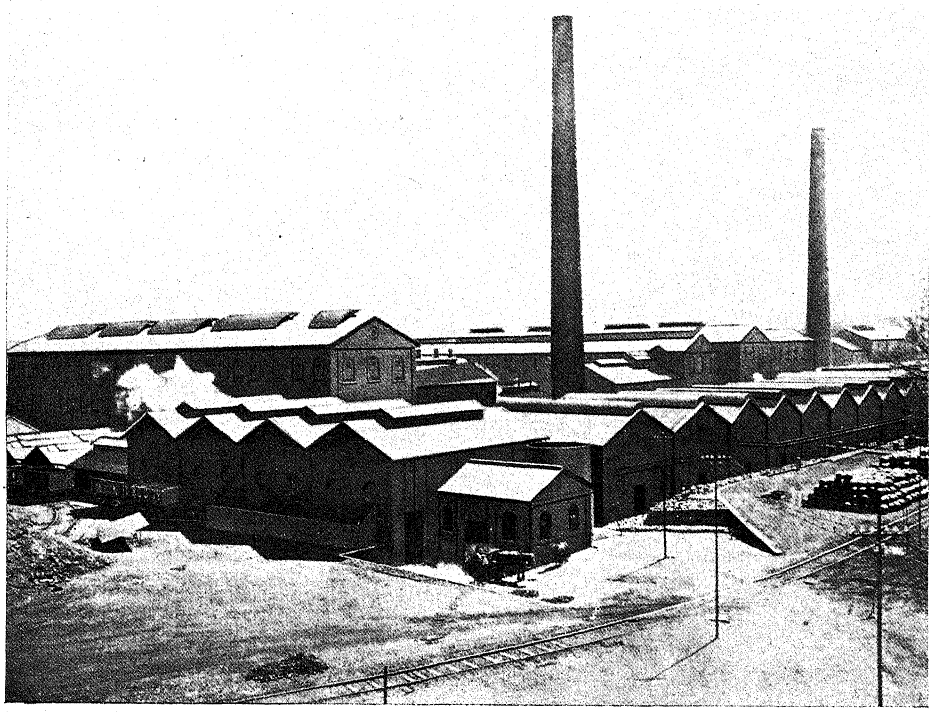


Fig. 82—Refinery, Mond Nickel Co., Clydach, Wales.

down, the flame became luminous and deposited on cold porcelain, a metallic film of pure nickel. Investigation then revealed the existence of a previously unknown compound of nickel with carbon monoxide, which was named nickel carbonyl, and which has the formula $Ni(CO)_4$. It is formed by passing carbon monoxide over metallic nickel at 50° C., but is completely decomposed into nickel and carbon monoxide by heating to 150° C. or higher.

In 1892, a large scale experimental plant was erected at Smethwick, near Birmingham, and after some years of patient work, during which the plant had several times to be reconstructed, the most suitable method of operation was arrived at, and the present works at Clydach (Fig. 82) were built. The process, as carried out here consists essentially of five operations:—

(1) Roasting, to drive off as much of the sulphur as possible. (2) The extraction of about two-thirds of the copper by sulphuric acid. (3) The reduction of the nickel and remaining copper to the metallic state by water gas or producer gas rich in hydrogen. (4) The volatilization of the nickel as nickel carbonyl by the action of carbon monoxide. (5) The decomposition of the nickel carbonyl, with deposition of metallic nickel and regeneration of the carbon monoxide.

The relation of these operations to one another, and the circuits performed by the roasted matte and carbon monoxide during the process, will be more clearly grasped by a reference to the accompanying flow-sheet (Fig. 83), reproduced from Roberts-Austen's paper.

The five operations referred to are described in detail below:—

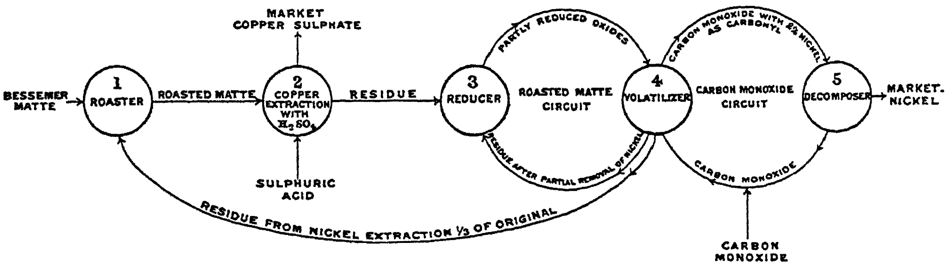


Fig. 83—Flow-sheet, Mond Refining Process.

1. Roasting

The bessemer matte received from Coniston containing about 40 per cent. nickel, 40 per cent. copper and 0.3 to 0.5 per cent. iron, is ground in ball mills to 60 mesh, and roasted in straight-line, double-deck calcining furnaces, where it is conveyed along the hearths by scrapers carried by an endless chain.

2. Extraction

The roasted ore, containing not more than 2 per cent. sulphur, is leached with 10 per cent. sulphuric acid, in lead-lined extractors. About 70 per cent. of the copper present is thus dissolved with 1 to 2 per cent. of the nickel. The treatment of the resulting copper sulphate is described later. The undissolved residue, containing about 51 per cent. of nickel and 21 per cent. of copper, is washed on lead vacuum filters, dried and transferred to the top of the reduction towers.

3. Reduction

This operation is carried out in vertical towers built up of 24 short cylindrical sections to a height of 40 feet. Each section contains a shelf, which is hollow, to permit heating by producer gas to a temperature of 350° C. The powdered residue from the leaching operation is carried as it descends, alternately from the centre to the periphery, and vice versa, by the action of stirrers or rabbles driven by a central shaft, as in an ordinary shelf roasting furnace. A current of water gas passing upwards through the tower, reduces the nickel and copper to the metallic state, and the ferric oxide to ferrous oxide.

4. Volatilization

The volatilizing towers are similar in construction to the reducing towers, but the shelves are not hollow, since no heating is required. The production of the nickel carbonyl and its volatilization, are carried out at a temperature of 50° to 80° C., which is easily maintained by the heat of the reduced matte and gas which enter the tower.

The reduced material from the previous operation, having been transferred to the top of the volatilizing towers by air-tight conveyors, is here subjected, as it descends, to the action of producer gas. The carbon monoxide of the latter forms with the metallic nickel, the volatile nickel carbonyl, which is swept on by the gas current to the decomposer. After passing through the volatilizer, the material returns to the reducer, and then again to the volatilizer, circulating in this manner for 7 to 15 days. About 70 per cent. of the nickel is thus removed, the residue containing approximately 30 per cent. of the copper and 30 per cent. of the nickel originally present in the roasted matte, together with about 5 per cent. of iron, as compared with the 0.5 per cent. or slightly more in the raw matte.

This residue is smelted with gypsum and reducing agents very much as is done with New Caledonian ore, whereby matte similar to the original 80 per cent. matte is reproduced. It is roasted and re-treated, and the residues, now containing but little nickel or copper, are set aside, and ultimately sold for their precious metal contents, of which the palladium and platinum constitute the principal value, although they contain also iridium, rhodium, gold and silver.

5. Decomposition

The gas issuing from the volatilizer and laden with the volatile nickel carbonyl, is conducted to the decomposers. These are of very ingenious design, and are intended to produce the nickel in the form of shot to obviate the difficulty and expense entailed in cutting up sheet or lump metal. The decomposer is shown in Fig. 84, which presents vertical sections of the apparatus on planes at right angles to each other. A is a cylindrical vessel, preferably built up of short cylinders, a a, bolted together; it contains a central tube, C, provided with gas outlet holes, O, through which the gas containing nickel carbonyl, entering at the gas inlet, B, passes into the vessel which is filled with shot, or small granules, of nickel. The gas passes through the interstices between these granules, and is brought into intimate contact with them, so that, as the nickel carbonyl is decomposed, the nickel is deposited on the granules. The gases finally escape through the outlets, L, into the gas-exit pipe, M. In order to prevent the granules cohering, they are kept slowly moving by continuously withdrawing some of the granules from the bottom of the cylindrical vessel, A, by means of a right and left-handed worm conveyor. U, which delivers the granules into two sifting-drums, N. The smaller granules fall upon an inclined plane, W, and collect at the base of the elevator, E, which conveys them again to the top of the cylinder, A, and feeds them through the feeding-hole, X. In order to avoid the deposition of nickel from the nickel carbonyl in the central tube, C, it is kept cool by causing water to circulate down the tube, F, and up through passages, F^1, formed in the central tube, to the water outlet, F^2. The cylindrical vessel, A, is surrounded by a wrought-iron casing, Q,

which forms heating-spaces, H, communicating with heating-flues, P, so arranged that the temperature of each cylinder can be separately regulated by dampers so as to maintain the temperature of the granules of nickel contained in the vessel, A, at about 200° C., at which temperature the nickel carbonyl is decomposed. To ascertain whether the cylinder, A, is full of granules, a rod, R, is fixed to the spindle of an external handle, which can be turned partly round so that, if the operator feels resistance to the motion of the R, it is certain that the granules extend to that height.

It will be obvious from the above description, that the shot are kept in continual motion, so have no tendency to cohere, while the deposition of the nickel produces a growth in concentric layers. To produce shot of about 1/8 in. in

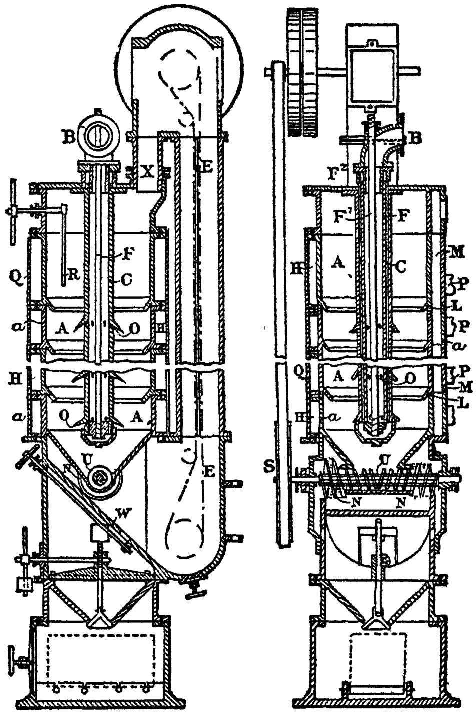


Fig. 84—Decomposer, Mond Refining Process.

diameter, requires about 2 months, while 3/8 in. in diameter necessitates 6 months. The material is screened and sold in various sizes to suit the market requirements; 28 lb. canvas bags are used as packages, and these are usually thrown bag and all into the alloying furnaces by the customers. The purity of the nickel is high, 99.8 per cent. or better, with a little iron and minute quantities of sulphur and carbon.

The Copper Sulphate

The copper sulphate prepared by treating the roasted bessemer matte with sulphuric acid, as already described, is a valuable product greatly in demand by the owners of vineyards in France, Italy, Spain, Portugal and Greece, to prevent mildew on vines, and is also employed in combating potato blight.

The impure solution from the extractors is concentrated and crystallized in vacuum pans, and collected on vacuum filters. These first crystals are re-crystallized in the ordinary way to either (a) fine crystals or (b) large crystals.

The fine crystals, which resemble granulated sugar in size, are sold only in France, owing to the prejudice entertained by the other countries against this particular form, a prejudice which is decreasing year by year.

The large crystals, which have been deposited on strips of lead, are removed, washed with a saturated solution of copper sulphate, and placed in a vertical cylindrical vessels which, when full, are allowed to drain and placed over openings through which slightly warm air passes upwards through the mass of crystals until they are dry. The temperature is kept sufficiently low to prevent efflorescence, which spoils the appearance of the crystals and renders them less acceptable. About 20,000 tons of copper sulphate are shipped annually from Clydach.

The mother liquors remaining after the crystallization of the copper sulphate from the extraction liquor are rich in nickel sulphate, which is also recovered in crystal form. At present about 1,000 tons are being produced per annum.

Production at Clydach

The output of the Clydach works in 1915 was about 5,000 long tons (of 2,240 lbs.) of metallic nickel, about 20,000 tons of copper sulphate containing slightly over 23 per cent. of copper, and over 1,000 tons of nickel salts carrying about 20 per cent. of nickel.

The producer gas and water gas required are made in the usual way from high class anthracite coal. There is a very large number of taps and valves in the various parts of the plant and, if bituminous coal were used, the deposition of naphthalene would cause much trouble. By employing the anthracite mined near by, containing at least 90 per cent. carbon with practically no volatile matter, these difficulties are avoided.

The poisonous nature of the above gases, and particularly the deadly effect of the nickel carbonyl, render imperative the greatest care in the maintenance of tight joints. An operator passes round at intervals with a small lighted torch whose blue flame at once becomes luminous in case there is leakage of the carbonyl at any joint to which the torch is applied. The carbonyl has a peculiar odour resembling ordinary soot, and persons with a delicate sense of smell can recognize an escape when there is less than one part of the carbonyl in a million parts of the air.

A visit to the works is impressive. The whole operations are carried out with a minimum of hand labour or even of control, and the work of the men, although most of them are highly skilled, consists mainly in seeing that the mechanism carries out its duties, and that there is no breakdown in any part of the operation, or any leakage of gas. A failure in the mechanism which maintains circulation and constant movement of the pellets of nickel in the decomposers, would cause the whole to become agglomerated. Such a mishap is very rare, but when it occurs, it means the putting of the whole decomposer out of commission for an indefinite period while the almost solid mass can be broken out.

The process may be described as one of great simplicity, but also of great delicacy, requiring the most skilled operators and control, accurate and elaborate

manufacture and fitting of parts, much engineering skill in erection and working, and metallurgical and chemical skill in control.

At the time of the Commissioners' visit to Wales, the company was just heating up a newly completed unit, and was contemplating additions by which the output of nickel could be increased to 10,000 or 12,000 tons.

The number of workmen employed, April, 1916, in Wales, was 1,176, about half the number employed in Canada. In the Mond as in the Orford and electrolytic processes, the amount of labour required in refining is much less than that in mining and smelting. The wages paid in Canada are about three times those paid in Wales.

New Caledonian Ores

As stated in the introductory paragraphs of this Chapter, the matte exported from New Caledonia is not 80 per cent., but a much lower grade product resulting from a blast furnace operation. On its arrival in Europe or the United States, this latter is first bessemerized, and the subsequent operations consist merely in roasting the matte to oxide, and reducing the latter to metal with carbon. These operations have already been described in the Chapter on Smelting.

Electrolytic Refining

A considerable number of processes have been proposed for the electrolytic refining of nickel matte, and many have been tried and abandoned, often for reasons which it is difficult to understand, and which had apparently no direct connection with their actual merits or commercial prospects.

Electrolytic treatment may be carried out on the unroasted or partly roasted matte, or on the matte after being roasted "sweet," i.e., practically free from sulphur. The matte is commonly cast into anodes, or the solution obtained by treating the roasted or raw matte with acid or other solvents may be electrolysed with the use of insoluble anodes, or, as is common, a combination of the two processes may be employed. Either the copper or the nickel may be deposited first, according to the conditions of deposition, voltage, etc., and a variety of solutions, of which sulphate, chloride and cyanide are the principal, have been employed. It is common for nickel to accumulate in the copper solutions, so that electrolytic processes often yield not only metallic nickel and copper, but nickel salts, and could be arranged also to produce copper salts.

The first electrolytic process tried in Canada was the Hoepfner process, owned by the Hoepfner Refining Company, Limited, of Ontario, and controlled by the Nickel-Copper Company of Ontario, Limited. A plant was erected at Hamilton in 1900 to work the Hoepfner method, but its use was given up, and the Nickel-Copper Company took over the process of Hans A. Frasch (U.S. patents Nos. 469,439 to 469,442—all four dated March 5th, 1901, and No. 669,899 dated March 12th, 1901). This process also, although very favourably reported upon,[1] did not prove a commercial success.

The advantages of an electrolytic method where current is cheap are obvious, and during the time the Canadian Copper Company, before its merger with the Orford Works, was dependent upon the latter for refining its matte, it expended much time and money in endeavouring to perfect an electrolytic process. The

[1] Eng. and Min. J., Sept. 8th, 1900, p. 272, and April 6th, 1901, p. 428.

Mond Nickel Company too, as Mr. Robert Mond narrates in his evidence printed in the Appendix, experimented for some time with the view of testing the possibilities of electrolytic refining. The consolidation of the Canadian Copper Company with the Orford Works in 1902 gave the united company control of the cheaply operated Orford process, and the Mond Company, after some preliminary difficulties, got its own ingenious refining process into successful operation. There was consequently little inducement for either company to search for new refining methods, and their failure to adopt refining by electrolysis cannot be taken as evidence against its feasibility in Ontario, where electricity is cheap and skilled labour available.

Advantages of Electrolytic Method

Important features in favour of electrolytic refining are the small quantities of chemicals required, the absence of objectionable waste liquors, the ease with which further units can be added as increased output is required, the comparatively small losses of nickel and copper, and the practically complete recovery of the precious metals.

The precious metals are a source of additional profit, and represent a considerably greater value than is generally supposed, although the amounts in the different mines vary greatly. This matter is discussed in Chapter X, under the heading of Recovery of Metals of the Platinum Group, and the increasing price and demand for platinum and palladium are there dealt with.

The British America Nickel Corporation, Limited, intends to employ electrolysis for refining, and has made arrangements with Mr. Victor M. Hybinette, whose process is in successful operation in Norway on much poorer ores than any which are being worked in Ontario, for the sole use of his process in North America. The following United States patents have been taken out by Mr. Hybinette: Nos. 805,555, 805,969, each dated Nov. 28th, 1905, 701,780 dated June 5th, 1912, and Nos. 1,128,313 to 1,128,316, each of the four latter being dated Feb. 16th, 1915, and assigned to the National Trust Company, Limited, of Toronto, Canada.

Specifications of the Hybinette patents 805,555 and 805,969, the leading patents, have already been published in Dr. Coleman's Report,[1] so that it is unnecessary to reprint them here. The process actually employed at the Kristianssands refinery in Norway differs in some respects from these descriptions, but the main principles of the Hybinette method are therein set out.

A member of the Commission was shown over the refinery of the Norwegian company, where the process is in full working operation. The following is as full a description of the process as the company is willing to have published, and although lacking in detail, may be taken as correctly outlining the process, and covering the general method of procedure. Mr. W. A. Carlyle, who is on the Board of the British America Nickel Corporation as the representative of the Imperial Government, has written a letter to the Commission, which is printed in the Appendix at page 131, as to the general utility of the process.

[1] The Nickel Industry, pp. 178-185.

The Hybinette Process

The bessemerized matte, obtained from the smelteries at Evje and Ringerike, contains about 80 per cent. of nickel plus copper (commonly 47 per cent. of nickel and 32 to 34 per cent. of copper) with about 20 per cent. of sulphur and from under 0.25 to 0.4 per cent. of iron.

The matte is received in a granulated form from the smelter, is roasted to remove the bulk of the sulphur, and leached with 10 per cent. sulphuric acid solution, whereby a large proportion of the copper with very little nickel is dissolved out, and the residue is melted down and cast into anodes about 3 ft. by 3 ft. 6 in. and nearly ½ in. thick. These anodes contain about 65 per cent. nickel and 3 to 8 per cent. sulphur, the remainder being copper with a trace of iron.

The electric current is purchased at 50 kroners (1 kr. equals 27 cents) per h.p. year, at 25,000 volts, and is stepped down, first to 220 volts (alternating current), and then converted to direct current at a voltage of usually not over 160 to 170 volts, and never so high as 220. The maximum call for current is 1,000 k.w. The cost for current is expected to be considerably lowered in the near future.

Recovering the Nickel

The plants for depositing the nickel and copper are quite independent. The electrolyte used for the nickel carries 45 grammes of nickel and from 3 to 5 milligrammes of copper per litre, and is supplied by rubber tubes to the cathode diaphragms. After circulation, it contains from 2 to 3 grammes of copper per litre and is passed over waste anodes, which deposit the copper and re-supply nickel to the solution. The action of the anodes resembles that of pig iron in the cementation of ordinary copper, except that the copper is deposited by nickel instead of by iron. The amount of waste anode obtained during the electro-deposition of the nickel (about 30 to 40 per cent. of the original weight) is said to be about sufficient for the purpose of rejuvenating the exhausted solutions from the nickel vats, and it is stated that the solutions never require to be thrown away, as the cementation purifies them sufficiently.

After the cementation, any waste anode fragments remaining after the cement copper has been cleaned off, are crushed, roasted, leached with 10 per cent. sulphuric acid solution to remove more copper, as with the original matte, and the residues are melted into fresh anodes and re-electrolysed.

The anodes for the nickel department are contained in special canvas bags obtained from Glasgow, and stated to last about 18 months. Paper diaphragms supported by common canvas to prevent breakage have been used when the supply of the special bags failed, and are said to have lasted as long as 12 months with careful handling.

The nickel cathodes are made of iron plates rubbed over with a thin wash of water and graphite. The nickel is deposited on both sides of the plate, so that each gives two sheets of nickel. The plates, 3 by 3½ in. in area, are arranged in parallel, and the voltage depends on the number of tanks in operation; 3 to 4 volts per tank is used according to the current density, which is 8 to 10 amperes per square foot. Two kinds of tanks are used; large tanks, each containing 20

cathodes and 21 anodes, and smaller tanks containing 10 to 14 cathodes and 11 to 15 anodes, i.e., in all cases, the number of anodes is one more than the number of cathodes. The nickel deposition takes about 10 days to complete. The deposited nickel weighs from 20 to 30 lbs. per sheet. The sheets of nickel are about 1/8-in. thick and have the usual corrugated and warty appearance, but are dense, the corrugations and warty or stalactitic growths being normal, and giving no trouble as regards short circuiting. After being washed in weak sulphuric acid to remove basic salts, the sheets are dried and cut up into oblongs about 2 in. by 3 in. for sale. They are not melted down or otherwise treated, as they are said to be preferred by the German market in the flat as cut from the sheet.

The metal is guaranteed 99 per cent. of nickel, but can be made purer. The copper does not exceed 0.1 per cent. (commonly as low as 0.03 per cent.) and the average iron content is 0.5 per cent. No attempt is made to remove the iron; the bessemerized matte carries very little to begin with, although it contained as much as 2 to 3 per cent. in the early days. The small contents of iron and other impurities are, in fact, negligible, as the premium for pure nickel is very small.

The precious metals become concentrated in the anode slime, which is melted up into fresh anodes and electrolysed separately, the final slime being sold direct for its precious metal contents.

Recovering the Copper

The copper is deposited very similarly to the nickel, but on copper sheets and without bags round the insoluble lead anodes. Anodes and cathodes are about the same size as for nickel. The copper takes about seven days for the deposition. The precious metals are obtained as in the case of nickel.

The current density is about 10 amperes per square foot of cathode at 2 volts, and there are commonly nine cathodes and eight anodes per tank, i.e., the reverse of the arrangement for the nickel deposition, in which the anodes exceed the cathodes by one in each tank.

The company has supplied the following figures among others, as to costs, etc., under pre-war conditions::—

General.	Approximate cost, kroners.
Coke	30.00 per ton
Sulphuric acid	5.40 per 100 kilos f.o b. Amsterdam
Coal	20.00 per ton
Wood	15.00 per cu. met.
Current	50.00 per H.P.
Voltage at which current is received	25,000 volts.

Analyses.	Ni	Cu	Fe	S	As	Co
Ore	1.60	0.90	....	....	....	....
Bessemer matte	47.00	32.00	0.18	....	....	....
Refined nickel	98.75	0.10	0.50	0.01	....	....
" copper	0.14	99.72	0.022	0.0103	0.0038	0.008

The refined copper carries about 0.10 per cent. graphite on the surface where stripped from the cathode.

Experiments by Prof. Guess

The Commission obtained the services of Mr. George A. Guess, Professor of Metallurgy at the University of Toronto, to carry on certain experimental work in the electrolytic refining of the Sudbury Bessemer matte. Following is Professor Guess' account of the work and the results obtained, which appear to be of importance. The experiments are not yet complete, but application has been made for patents covering the improvements in Canada, the United States and Great Britain, the patents when obtained to be the property of the Ontario Government.

Work was started in January, 1916, looking for an electrolytic method of separating and refining copper and nickel in copper-nickel mattes During January, February and March of 1916 experiments were carried out in the metallurgical laboratories of the University of Toronto. I was assisted in this work by Mr. A. G. Burrows, of the Bureau of Mines. Work was resumed in October, and the investigation is still in progress. In October Mr. Burrows could not be spared by the Department, so I secured the services of Mr. A. L. Clarke as chemist.

A method has been worked out whereby copper and nickel may be refined. The investigation is still under way, and this must be considered as a preliminary report.

The raw material is what is known as bessemer matte, and is the product turned out by the basic converters at the copper-nickel smelters in the Sudbury district. This matte represents the final stage of the smelting process as at present carried out in Ontario, and it is this material which is now being shipped away for further refining.

The Canadian Copper Company produces matte containing about 56 per cent. nickel, 24 per cent. copper, a small amount of iron, and the balance sulphur. This matte is crushed to 20 mesh and roasted at a low temperature to about 2 per cent. sulphur. The calcined matte is leached with 10 per cent. sulphuric acid solution (100 grns. H_2SO_4 per litre). About 50 per cent. of the copper is extracted. The recovered solution will contain about 4.5 per cent. copper, .8 per cent. nickel, and 1 per cent. free acid. This solution is the electrolyte.

The leached residues are dried, reduced and fused in a furnace and cast into suitable anodes which will contain 80 per cent. nickel, 18 per cent. copper, and 2 per cent. iron. With these as anodes, copper starting-sheets as cathodes, and the recovered solution as electrolyte, cathode copper is produced, as in the precipitation of copper from sulphuric acid leaching of copper ores. The advantage is that with the soluble anode used, much less power is required than in ordinary copper practice, where an insoluble anode must be employed. Good cathodes are obtained until the copper in the electrolyte is reduced to 1.4 or 1.5 per cent. These cathodes represent about 77 per cent. of the copper dissolved by leaching. A current density of 16 5 amperes per square foot has been found satisfactory.

The electrolyte, when reduced to 1.5 per cent. copper, passes through similar tanks, the purpose of which is to reduce the copper content further, and to increase the nickel content by solution of the anode. A higher current density may be used here to advantage. A considerable amount of the copper from these tanks may be recovered as cement copper, but the relative percentage has not been determined.

With the soluble anode the copper content of the electrolyte may be reduced to 0.05 per cent. copper (.5 grains per litre). The nickel content will now be about 5.5 per cent., due to the solution of the anodes. The electrolyte runs next to tanks with insoluble anodes (hard lead), in which the copper content is reduced to .13 grains per litre, 0.013 per cent.

The solution now contains about 5.5 per cent. of nickel as nickel sulphate, a small amount of acid, and some iron as ferrous sulphate. If pure nickel is required this iron must be removed. This is done in a manner similar to the removal of the iron from zinc solutions, before the production of electrolytic zinc. The iron is oxidized to the ferric condition by manganese dioxide, and precipitated with nickel carbonate. The solution after filtration consists of nickel sulphate with a small amount of manganous sulphate.

In order to obtain good cathode nickel from such a solution, it is necessary to use a high current density, and to begin with a hot solution, about 75° C. The current keeps the electrolyte hot. It is necessary to add a small amount of glue to the electrolyte at intervals, 40 milligrammes of glue per litre of electrolyte, or 40 parts per million. Insoluble lead anodes are used. As electrolysis proceeds, the electrolyte becomes more acid, and the current efficiency goes down. Just how far electrolysis should proceed will depend on power and operating costs, and the extent may be controlled at will. I have assumed the economic limit to be half the nickel contained in the electrolyte, which may be removed with a current efficiency of approximately 50 per cent. A current density of 250 amperes per square foot is satisfactory. At a lower current density a hard green deposit forms on the cathode. This

appears to be a nickel oxide of approximately the formula Ni_2O_7. At still lower current densities, little or no nickel is deposited, the current efficiency dropping to a very low percentage.

The electrolyte leaving the nickel plating tanks will contain about 4.4 per cent. free acid. It is run to evaporating pans which remove as much of the nickel as possible as crystalline nickel sulphate. This is dissolved in hot water, serves as a storage electrolyte, and completes again the circuit of the nickel tanks. The acid liquor may be heated in iron vessels until anhydrous nickel sulphate is formed. The acid is drawn off, the anhydrous salt washed with water, and finally dissolved in hot water. This may be used conveniently as a source for nickel carbonate, using soda carbonate as a precipitant.

The acid and the washings are made up to strength, and used for further leaching of calcined matte. A certain amount of the manganese may be recovered from the nickel tanks. It is quite possible, however, to dispense with the manganese through oxidizing the iron by means of air and violent agitation.

It will be seen from the details as at present worked out, that there should be a certain ratio between the copper and the nickel in the matte, in order to give the best economic results. The reason is as follows:—the total copper in the matte treated per day is thrown out by electrolysis, practically all of it while the copper-nickel anodes are being dissolved. In order to dissolve the daily production of anodes a certain number of ampere-hours are necessary, and these should correspond approximately with the ampere-hours necessary for precipitating the copper. A matte containing about equal amounts of copper and nickel, such as the product of the Mond Company at Coniston, preserves the balance nicely. It is, of course, always possible by prolonging the treatment in the second series of copper tanks and adding some acid, to increase the solution of the anodes, so that a certain flexibility is obtainable. Further investigation may allow a greater latitude in the composition of the mattes.

A Possible Process for Copper Concentrates

The following suggestion is offered at present. We have adjacent to the Sudbury district a number of small deposits of copper, the product from which is likely to be flotation concentrate. There are no reverberatory furnaces in Canada treating copper ores, so that there would be difficulty in marketing such a concentrate in Canada. It has for some time appeared to me that such material, if not gold or silver-bearing, might to advantage be treated by roasting, sulphuric acid leaching and electrolytic precipitation. To do this work in connection with nickel refining as herein outlined, would give the advantage of a soluble anode for the precipitation of the copper, and thereby reduce the power required from 30 to 50 per cent. At the same time, a market would be provided for such a copper concentrate, and refined copper would be produced therefrom.

CHAPTER X

Recovery of Metals of the Platinum Group

Introduction

Although the presence of gold and silver and of metals of the platinum group in practically all nickeliferous pyrrhotites throughout the world has long been known, their importance in connection with the Ontario nickel industry is even now practically unrecognized, except by those who recover and sell them.

The nickel-copper ores of Sudbury are capable of producing much more palladium than the whole of the present world's supply, together with a very large proportion of platinum, iridium and other metals of the platinum group. The quantity of palladium present is much in excess of the platinum. It may be mentioned that the assay of ores and mattes, and of other metallurgical products, for palladium, is exceedingly difficult, and that the results published are often unreliable. They are commonly too low, so that the official or private figures given by the companies or otherwise obtained, are not likely to be too high. The recovery of palladium is also much more difficult than that of platinum or other metals of the platinum group, so that both the assay values reported and the recoveries which have been made, are undoubtedly lower than they should be. Anything which can be done to encourage the better recovery of these metals, or enforce the use of refining processes which recover them, would be justifiable, and particularly so now that platinum and palladium are increasingly required, and stand at so high a price. It may be mentioned that, apart from the Mond Nickel Company's method, the processes most likely to recover these metals are the electrolytic methods of refining.

Platinum Group of Metals

The platinum group of metals includes platinum, palladium, iridium, rhodium, ruthenium and osmium. Of these, palladium occurs in the largest proportions, then platinum, iridium and rhodium in the order named. Although ruthenium and osmium are present, there are no records of the recovery of either, and it is probable that the bulk of the osmium would be lost by volatilization during the smelting to matte. It may be taken as axiomatic that no member of the platinum group is found in a mineral or ore deposit without the others, although one may predominate, and some be present only in traces. In the true native platinum deposits which yield the bulk of the platinum of commerce, this metal is greatly in excess of the others, but in mixed sulphide ores, including copper ores, palladium almost invariably predominates. The first metal of the platinum group to be discovered at Sudbury was platinum, found in the mineral sperrylite. Sperrylite is essentially an arsenide of platinum, and analyses of the pure isolated mineral have shown up to over 50 per cent. of platinum, and from 0.5 to 0.75 per cent. of rhodium, but only a trace of palladium. It is curious that although the occur-

ence of sperrylite would account for the platinum and rhodium which occur in the Sudbury matte, it does not account for the palladium, albeit that metal occurs in greater quantity than any other member of the platinum group in the Sudbury ores, and in fact, in all pyritic nickel ores throughout the world.

The association of rhodium with platinum in sperrylite is interesting, as it is one of the platinum metals which the International Nickel Company produces, and specifically mentions as one for which it receives payment. This, no doubt, is mainly obtained from the Vermilion mine ore, which that company treats as far as possible, separately from its other ore.

Palladium has never been traced to any definite mineral in the case of nickel ores, but like the gold and silver, is commonly found in greater quantity in the more cupriferous varieties, and almost certainly as a nickel-palladium or nickel-copper-palladium mineral. This view is confirmed by the fact that such copper ores (represented by the blister copper obtained from them) as carry the most nickel, are almost invariably the richest in palladium as well as in platinum. The amount of palladium where much nickel is present, is especially noticeable. According to S. Pina de Rubies[1] native platinum always shows the spectrum of nickel, and more strongly when iron is present.

Recoveries from Blister Copper

In this connection, it may be stated that the blister copper obtained from practically all the sulphide copper ores throughout the world contains not only gold and silver, but also the metals of the platinum group, and that the electrolytic copper and bullion refiners are recovering increasing quantities year by year, partly through a tardy recognition of their presence, but mainly through extra care in endeavouring to recover them.

The U.S. Geological Survey[2] reports as follows:—

According to the reports received from the refiners of platinum, gold bullion, and blister copper, 8,665 troy ounces of refined new[3] metals of the platinum group were recovered, of which 1,587 troy ounces are believed to be of domestic origin.

New platinum and allied metals recovered by refiners, 1914-1915, in troy ounces.

Year.	Platinum.	Iridium.	Iridosmine-osmiridium.	Palladium.
1914	3,430	64	195	2,635
1915	6,495	274	355	1,541

These figures are not as complete as could be desired, and are probably several hundred ounces below the actual production. The platinum situation has been so disquieting during 1915 that refiners have been loath to give much information, either as to the sources from which their supplies have been derived, or as to the actual results of their operations. It is hoped, however, that another year will see more stable conditions.

The U.S. report for 1913 states that 1,100 ounces of refined platinum were produced in that year from "foreign and domestic matte and bullion," and that more palladium was recovered "on account of greater care in treating the slimes of copper refineries."

[1] Arch. Sci. Phys. Nat., 1916, V. 41, pp. 475-8.
[2] Platinum and Allied Metals in 1915, published Aug. 15th, 1916, p. 139.
[3] New, as distinguished from metal recovered from scrap.

Concentration of Precious Metals in Matte

As regards both nickel and copper ores, it is true that the quantity present in the ore is so low in the case of the silver, gold, platinum or palladium and other metals of the platinum group, that it would not be worth treating for the sake of recovering them alone, but the smelting process concentrates the whole of them automatically in the matte, so that a ton of matte may contain from 15 to over 20 times as much of each as was present in a ton of the original ore, depending upon the number of tons of ore smelted per ton of matte produced. The processes of refining similarly concentrate these metals into certain products obtained during the refining, thus effecting a further concentration. As regards concentration in the matte, the recovery by each company up to that point is practically complete, but the conditions as regards the subsequent treatment, i.e., the refining, are entirely different.

By the Mond or electrolytic processes, it is possible to save practically the whole of the precious metals, and both methods actually recover a large proportion in the form of a by-product which is sold on the basis of its precious metals contents.

In the case of the International Nickel Company, however, although the combined metallurgical and chemical treatment of the matte results in a considerable amount of concentration of the precious metals, a large proportion goes into the nickel and is thus lost, and similarly, a considerable amount goes into the Monel metal, of which the company makes a large quantity (carrying from 5 per cent. to 10 per cent. of the total nickel in the matte produced at Copper Cliff). This is also lost. Certain products obtained during the treatment of the matte by the International Nickel Company are refined electrolytically, and the precious metals in such products are recovered and sold. Similarly, the company commonly treats the matte from the Vermilion mine, which is unusually rich in platinum, as a separate operation, and a considerable proportion of the precious metals which it sells, is thus obtained.

Associations with Copper

It is extremely difficult to determine the exact proportion of the platinum metals present in nickel ores, except in the cases of specially selected rich specimens, and it is impossible to state how much is present in the tonnage extracted from month to month or year to year, partly on account of the difficulty in sampling, but mainly because different portions of all deposits vary greatly as regards the amount of platiniferous mineral present. As a rule, silver and gold occur in greater degree in the more cupriferous parts, but although the same is also true to a great extent as regards the platinum, iridium and rhodium, it does not appear to be definitely proved as to palladium. Such mines or portions of a deposit as yield most palladium, are usually richer in copper, but this appears to be due rather to the occurrence of an unknown cupriferous palladium mineral than to a segregation of palladium in copper ores. This is the case throughout the world, including Norway, Tasmania and South Africa, where specimens or small zones extraordinarily rich in palladium, are occasionally found as in Sudbury, although the average content of any commercially worked deposit is lower than

that of Sudbury or of other nickel-bearing deposits in Ontario, such as that of the Alexo mine.

The garnierite of New Caledonia or other "oxidized" ores, may be regarded as not containing sufficient gold, silver or platinum-group metals to be worth consideration. This is due to the fact that the nickel has commonly been leached out, carried away in solution and re-deposited at a distance from the parent deposits, in which any of the precious metals which were originally present, have been left.

Proportions Present in Sudbury Matte

Although it is not possible to state correctly the actual quantity of the platinum metals present in the ores mined, the quantity recovered per ton of ore can be accurately determined from assay of the matte, provided the number of tons of ore smelted per ton of matte produced is known.

In the year ending Dec. 31st, 1916, the total ore smelted in the Sudbury district was 1,521,689 tons, with production of 80,010 tons of matte, of which the Canadian Copper Company produced 63,567 tons, and the Mond Nickel Company, 16,443 tons.

The Canadian Copper Company reports that the average content of precious metals per ton of matte for the three years ending 1915 was roughly as follows:—

Gold	0.05 oz. troy
Silver	1.75 "
Platinum	0.10 "
Palladium	0 15 "

The figures given by the company for an isolated month in 1915, were higher, as were also figures obtained by the Commission on samples received from the company in 1916, but the above may be taken for the purposes of calculation.

The matte produced by the company in the fiscal year ending March 31st, 1916, amounted to 56,405 tons which, on the above basis, would contain 5,640 oz. platinum and 8,460 oz. palladium.

The recovery of these metals by the International Nickel Company in that year amounted to 1,093 oz. of platinum plus palladium, together with 257 oz. of other metals of the platinum group, mainly rhodium and iridium.

The Mond Nickel Company has not furnished figures as to the precious metal contents of its matte, but from assays made on behalf of the Commission on samples obtained from that company, it would appear that the matte produced by the Mond Nickel Company is considerably richer in metals of the platinum group than that from the Canadian Copper Company.

The U.S. Geological Survey[1] gives the following as what may be considered "fair average values" for the years 1914 and 1915:—

	1914 $ per oz.	1915 $ per oz.
Platinum	45	55
Iridium	65	83
Palladium	44	56

[1] Mineral Resources, Platinum and Allied Metals in 1915, p. 142.

It is pointed out that the price for platinum rose regularly in 1915 with an occasional set-back, to $85.50 in December, and it may be added that the quotation in February, 1917, was from $100 to $105 per ounce.

Taking the basis of $50 which the U.S. Geological Survey regards as a fair average for platinum or palladium, and ignoring other metals of the platinum group, although they represent a considerable additional amount and are worth more per ounce, the weight and value of the platinum and palladium in the 63,567 tons of matte produced at Copper Cliff in the year ending Dec. 31st, 1916, would be 15,892 oz. worth $794,600, a figure which may be regarded as conservative.

Large though the figure is, it represents only the platinum metals actually present in the matte, such additional amounts as may have been present in the original ores and lost in smelting them to matte, being ignored. Hence, such recoveries as are made by the refining companies represent only the percentage recoveries on that present in the matte, and would be still lower on that in the original ores.

International Nickel Company's Recoveries

The following table[1] shows the recoveries of the precious metals by the International Nickel Company over a period of years, together with the quantities of matte refined. The company points out that during part of the period covered by these figures, it was treating material from other sources, so that the whole of the recoveries could not be attributed to the Sudbury matte:—

Year	Matte Treated	Gold	Silver	Platinum	Palladium
	tons	oz.	oz.	oz.	oz.
1907	17,840	993.572	63,400.70	226.800	607.300
1908	18,839	5,238.181	139,329.29	172.316	382.287
1909	18,407	2,113.669	63,138.66	546.627	1,270.598
1910	24,309	2,649.799	60,256.83	258.325	522.804
1911	26,840	2,203.052	70,954.38	665.552	753.363
1912	27,653	2,476.558	62,169.66	496.850	680.130
1913	38,733	2,336.405	77,924.03	292.863	298.780
1914	40,267	....	....	1,437	
1915	31,428	....	....	....	....
1916	56,405	3,953.000	114,975.00	1,093	

In 1916, 257 ounces of other platinum metals, mainly, rhodium and iridium, were also recovered.

The low value placed by the different companies upon the platinum metals content and upon that of the precious metals generally, including the gold and silver, is shown by the fact that the Mond Nickel Company estimate that their ore reserves will yield not over 70 cents precious metal values per ton of ore, and the British America Nickel Corporation, $1.00. An assay made by Ledoux and Company on a parcel of between 5,000 and 6,000 tons of ore shipped from the Alexo mine in 1915 showed 0.03 oz. of platinum and palladium per ton of ore. The Norwegian ore appears to yield about 50 cents per ton of ore. The Tasmanian

[1] 22nd Annual Report of the Ontario Bureau of Mines, 1913, Part 1, pp. 26 and 27; Report on the Mineral Production of Canada during the calendar year 1915, pp. 58 and 59, with additional figures obtained from the company.

ore has not been smelted alone, so that the recoveries cannot be given, but one large parcel is stated to have contained 0.06 oz. of platinum per ton. Palladium was not tested for.

As regards the nickeliferous pyrrhotite of the Insizwa Range in Griqualand, assays for the precious metals vary considerably. They, however, show that the metals of the platinum group occur in useful proportions. A number of analyses of picked specimens or small parcels have been published by the Imperial Institute,[1] the Dominion Royal Commission[2] and W. H. Goodchild.[3]

Bearing in mind the normal and particularly the present and future demands for all metals of the platinum group, investigations should be continued, both as to the amounts present and the possibility of increasing the recoveries. It need scarcely be pointed out that the electrolytic process of refining nickel matte acquires added value from the fact that it recovers these metals automatically at practically no additional cost.

Palladium has long been used in dentistry, and is now largely replacing platinum, both in that work and in jewellery. It has risen in price since the war began until now it possesses as high a value as platinum, which it is likely to replace still further both in the above and other industries. It may be mentioned that, in 1914, the National Jewellers' Board of Trade of New York prepared a bill for presentation to the New York Legislature forbidding the marking of jewellery as "platinum, pure platinum or solid platinum" unless containing at least 95 per cent. of metals of the platinum group, and that the Swiss Federal Council passed a law in the same year authorizing the official stamping of an "Alpine goat" on articles containing a minimum of 95 per cent. of platinum.

Assay by Ledoux and Company

Two samples of roasted nickel-copper matte from Sudbury were sent by the Commission to Messrs. Ledoux and Company, New York, to be assayed for their precious metal contents. Before roasting, sample No. 1 contained Ni. 55.4 per cent. and Cu. 23.5 per cent.; sample No. 2, Ni. 41.1 per cent. and Cu. 45.4 per cent. Ledoux & Co. reported the following results, 28th December, 1916:—

——	Sample No. 1		Sample No. 2	
Silver	1.84 1.84	1.84 ozs.	6.15 6.16	6.155 ozs.
Gold	0.026 0.028	0.027 "	0.256 0.256	0.256 "
Platinum	0.115 0.132	0.1235 "	0.990 0.986	0.988 "
Palladium	0.190 0.204	0.197 "	0.979 0.989	0.984 "
Iridium	0.045 0.047	0.046 "	0.065 0.065	0.065 "

All results in ounces Troy per ton of 2,000 lbs. Av.

[1] Bulletin, V. 14, No. 2, April to June, 1916, pp. 246 and 247.

[2] Report of the Royal Commission on the Natural Resources, Trade and Legislation of certain portions of His Majesty's Dominions, Minutes of Evidence taken in the Union of South Africa in 1914, Part II, 1914, pages 8 and 9. Evidence of Dr. Alex. Du Toit, Geological Surveyor, Cape Province.

[3] Inst. Min. and Met. Bulletin No. 148, Jan. 11th, 1917, pp. 3 and 6.

CHAPTER XI

Recovery and Utilization of Sulphur

Introduction

Large quantities of sulphur are expelled in the form of sulphurous acid (SO_2) in roasting, smelting and refining the Sudbury nickel-copper ores. The larger proportion is driven off on the roast heaps under the worst possible conditions for agriculture, as the roast heaps are low-lying, and the gas, which is about two and one-fifth times as heavy as air, flows along the ground unless carried away by the wind. Sulphurous acid is very soluble in water, and is therefore carried down in excess by rain or absorbed by moisture.

The roast heaps have been designedly placed where farming would never have been a flourishing industry, and the recent withdrawal from sale or settlement of certain areas of Crown lands, mostly non-agricultural in their character, has resulted in the roast heaps of the Canadian Copper Company being removed to a district where the objections are less serious. It may be said that the companies have done everything possible to minimize damage from roast yards. However, the importance of the matter is proved by the fact that one company alone (the Canadian Copper Company) constantly has roast heaps in operation carrying a total of about 250,000 tons of ore in about 100 heaps each about 100 ft. by 40 ft. by 8 ft. deep. About two-thirds of its total ore is treated in this way.

The Mond Nickel Company adopted the same practice at the beginning, but abandoned it during the summer months in 1916, and is making arrangements which may soon result in the total abolition of its roast heaps. This is interestingly shown in the following extract from a letter to the Commission under date February 21, 1917, from Mr. C. V. Corless, manager at Coniston:—

"... We have been running for a month or two, experimentally, with no roasted ore (from roast heaps) whatever on the charge, using only the proper proportion of sinter that the normal ratio of fines would make, should we abandon heap-roasting altogether. We intend running for some months in this way, while collecting full data for the final calculation as to the economy of the practice. While we are succeeding technically, the calculation as to the economy is much more complicated than would appear at first sight, so that at present I can offer no opinion on the economy of this practice. As winter roasting eliminates all damage to neighbors from the roast yard, the question as to abandoning heap-roasting altogether will be purely one of economy. My present feeling is that heap-roasting will be eliminated from our operations entirely within a year or two. . . ."

The British America Nickel Corporation, Limited, whose plant is now in course of erection, does not propose to use roast heaps. It is, in fact, likely that heap roasting will gradually disappear as methods for smelting unroasted ore are perfected. The Norwegian companies do not employ roast heaps, and have even given up smelting during the summer months, in order to avoid the heavy damages which they previously had to pay to the owners of forests in the vicinity.

The Quantity of Sulphur Liberated

Assuming the ore to contain 25 per cent. of sulphur, and to be roasted on the heaps to 10 per cent., every million tons of ore would yield at the roast heaps 150,000 tons of sulphur, i.e., 300,000 tons of sulphurous acid gas, which would be sufficient to produce 450,000 tons of ordinary strong sulphuric acid.

At the smelters, it may be taken that for every million tons of ore treated, about 50,000 tons of sulphur in the form of 100,000 tons of sulphurous acid gas, is discharged from the stacks. This would be capable of producing a further 150,000 tons of sulphuric acid.

Finally, at the refineries, not less than an additional 10,000 tons of sulphur, in the form of 20,000 tons of sulphurous acid gas, capable of producing 30,000 tons of sulphuric acid, is expelled from the stacks.

We have thus a total of at least 210,000 tons of sulphur discharged in the form of 420,000 tons of sulphurous acid gas for every million tons of ore mined. We can therefore estimate that, at the present rate of production, not less than 300,000 tons of sulphur, capable of producing nearly a million tons of ordinary sulphuric acid, is annually lost, and does damage through being allowed to escape.

The Sudbury companies have given the subject of the utilization of sulphur considerable attention, but it has not been found economically possible to make use of this material.

Sulphur from smelter chimneys may be diluted with air before escaping into the atmosphere to bring it below a fixed minimum, such, for instance, as that fixed by the British Alkali, etc., Works Regulation Act, 1906, i.e., the equivalent of 4 grains of sulphuric anhydride per cubic foot at 60 degrees F. and 30 inches barometric pressure. This limit has been fixed mainly for the benefit of such companies in Great Britain as cannot economically recover the sulphur.

The Canadian Copper Company paid during the year ending March 31st, 1916, $137,398 for "smoke damages," and, although the Mond Nickel Company's new practice of roasting only during the winter months will avoid this expense, the loss of sulphur will, of course, be the same from the conservation point of view.

Desirability of Saving the Sulphur

The solubility of sulphurous acid gas in water, its ready absorption by moisture, and the fact that the gas itself liquefies at temperatures common in Ontario during the winter, are factors in favour of roasting during the winter only (if such proves feasible, as there is every reason to expect), while the broader question of actual economical recovery is under consideration.

In the United States, Spain, England and many other countries, the recovery of sulphur and other noxious gases has ultimately resulted in the establishment of important industries which increase the utilization of their natural resources, and benefit both producers and users. It is impossible for the moment to see how the whole of the sulphur in the Sudbury ores can be efficiently dealt with, either in the form of sulphurous acid, by making sulphuric acid, by converting the sulphur into sulphate of soda, or recovering it as elemental sulphur. Sulphurous acid gas, as such, can be utilized in the paper pulp and many other

industries, but it would not apparently be feasible to erect such plants where the sulphurous acid is available. It could be converted into sulphuric acid and transported in tank cars for a limited distance only, owing to freight charges.

It may be noted that the United States produced, in 1916, over 950,000 tons of sulphuric acid as a by-product from the roasting of copper and zinc ores. This is nearly twice the amount produced in 1911, and represents about 25 per cent. of the total sulphuric acid made in the United States, the remainder being obtained by roasting sulphur or pyrites specially purchased for the purpose.

It is of interest to mention here that the saleable percentage recovered is of but little consequence, i.e., that high efficiency is of less importance than the prevention of nuisance, and to refer to the fact that, instead of recovering the sulphur as free sulphur or converting it into sulphuric acid, it may be used direct by the Hargreaves process for making sulphate of soda, which is one of the essential chemicals used by the International Nickel Company in the refining of the matte sent from Ontario to the United States, and which is also one of the primary materials used in the glass industry.

It must, of course, be remembered that the abolition of the roast heaps would not prevent the ultimate escape of the sulphurous acid into the air; but it can be expelled from the chimneys in a diluted form. It is essential to drive it off from the ore, either before or during the smelting and refining.

Losses of Metal from Heap Roasting

In addition to nuisance, it is important to remember that the roasting of the ore in heaps, although, at first sight, cheap, economical and efficient, deserves by no means to be considered as good metallurgical or chemical practice. The result of the roasting is very irregular, and although this is a matter of practically no direct importance in connection with the smelting and refining, the heap roasting leads to considerable loss of nickel and copper, particularly the former. This is commonly overlooked, and frequently not admitted by the smelters, but it is due to the fact that, although the roasting in Ontario is conducted with a view to merely removing the excess sulphur so that sub-sulphides of nickel, copper and iron are produced, a considerable amount of the sulphate of each metal is produced by oxidation, at the same time. This is especially the case with small roast heaps, and in such portions of the large roast heaps as are most exposed to the air. Although some of the sulphates are basic sulphates and not soluble in water, most are soluble and dissolve in such rain as may fall upon the roast heaps and not be evaporated by the heat. In other words, any water draining from the roast heaps, will be highly charged with nickel salts, and to a lesser extent, with copper salts. There is reason to think that the losses in this form, especially of nickel, are not negligible, and although the prevention of these losses alone might not justify the giving up of roasting in heaps, it is an important additional reason for abandoning roast heap practice. It is impossible to determine what these losses are, and it is impracticable to avoid them in roast heap practice.

Certain figures which the Commissioners have obtained indicate a loss of not less than 2 per cent. of the total quantity of nickel and copper in the ore roasted. This loss is probably mainly nickel, and, although not very large as a percentage

is heavy in the aggregate, and has to be added to the unavoidable losses in smelting and refining. It forms another valid reason, both as a matter of conservation of resources and of profit to the smelters, for considering the advisability of abandoning heap roasting.

The elimination of the roast heaps would be beneficial also in improving the practice of preparing the ore at the mine for roasting in the Wedge furnace, as carried out at Copper Cliff, or in the Dwight-Lloyd furnaces as at Coniston, or in any other type of roasting furnace. The Commissioners would point out that this is not put forward as a new suggestion on their part, as they are aware of the large amount of experimental work which has been done by the Canadian Copper and Mond Companies on these lines.

In the foregoing, the general aspects of the difficulties attending the discharge of sulphur dioxide from roast heaps and smelter stacks have been discussed, and the conclusion arrived at by the Commission has been stated. Attention will now be directed to some of the methods by which these difficulties might be attacked.

Utilization of Sulphur Dioxide

Although sulphur dioxide has a number of direct uses in various industries, only some of the methods of utilization or disposal have any importance in the present connection. They may be classified as follows:—

1. Sulphur dioxide is a necessity for the manufacture of (*a*) sulphuric acid; (*b*) paper pulp by the sulphite process; (*c*) sodium sulphate by the Hargreaves process.

2. Sulphur dioxide may be reduced to elemental sulphur by several processes, including: (*d*) the Hall process; (*e*) the Thiogen process.

These uses are dealt with in sequence below.

Sulphuric Acid

Sulphuric acid is manufactured at the present time by two entirely distinct processes, viz., the chamber process, and the contact process.

In the United States, two smelters use part of their furnace gases for making sulphuric acid by the chamber process. These are the Tennessee Copper Company and the Ducktown Copper, Sulphur and Iron Company, which operate plants adjacent to one another near the southeastern corner of Tennessee.

A minimum content of 4.5 to 5 per cent. of sulphur dioxide in the gases is necessary for satisfactory operation, and this results in the discharge of the poor gases from the high grade matte furnaces and from the converters, through a high stack.

Pyritic smelting is practised, i.e., green or unroasted ore is charged to the blast furnaces in the first operation, the sulphur being oxidized by the blast, and serving in part as fuel. The gases from these furnaces contain about 5.5 per cent. sulphur dioxide and are sent to the chamber plant for conversion to sulphuric acid.

The U. S. Geological Survey[1] reports a production by copper smelters of 360,522 tons of sulphuric acid reduced to 60° Baumé, valued at $2,749,633, which practically represents the output of these two plants.

[1]Sulphur, Pyrite and Sulphuric Acid in 1915, issued Sept. 23, 1916, p. 304.

The waste gases from the roasting of zinc ores in the United States have been utilized by the contact process. The United States Geological Survey report[1] states that, in 1915, zinc smelters produced 484,942 tons of sulphuric acid (calculated as 60° Baumé) valued at $4,292,493. Although the strength has been quoted as 60° B. for convenience, much of the acid produced by the contact process or otherwise from zinc smelteries, was considerably stronger, and a good deal of it was of the nature of "oleum," as required for the manufacture of explosives.

Uses of Sulphuric Acid

The uses of sulphuric acid are very numerous, and reference can be made here only to one or two of those for which large quantities are required.

For the conversion of natural phosphates into superphosphates for fertilizing, enormous quantities of sulphuric acid are used in the United States. While Canada possesses deposits of phosphate of lime in the Ottawa valley, they are expensive to work as compared with the phosphate deposits of the southern States, which are soft and easily excavated. Our phosphate industry has languished and died through the competition of the United States product, and there is but little prospect of an outlet for sulphuric acid in this direction.

Another of the large uses of sulphuric acid is the petroleum refining industry, but here again, the smelting plants are distant from the districts where petroleum is produced or refined. Another outlet available is for the galvanizing and tin plate producers, who employ the acid for pickling or cleaning the steel before it goes to the metal baths.

In Europe, large quantities of sulphuric acid are required in the Leblanc process for producing sodium carbonate and hydroxide from salt, but this industry is not carried on in America. Salt cake is an intermediate product of the Leblanc process, and is used by the Orford Copper Company in its refining process, but the total amount required would only be a small fraction of the production if the sulphuric acid produced from Sudbury ores were thus employed. A by-product in the Leblanc process in muriatic or hydrochloric acid, and the disposal of the large quantities produced would appear to be very difficult.

At the present time, under war conditions a large quantity of sulphuric acic is being consumed in Canada in the explosives industry. With the cessation of war orders, this consumption will be greatly curtailed, and since practically all the industrial countries are producing explosives in great quantities, an export trade in them at the conclusion of the war is out of the question, and the domestic consumption of explosives in Canada is small.

An excellent idea of the relative importance of these various outlets for sulphuric acid is given by the following estimate by Mr. Utley Wedge, of Ardmore, Pa., of the quantities, in terms of 50° Baumé acid per annum, consumed in the United States:—

Manufacture of fertilizers	2,400,000	tons
Refining of petroleum products	300,000	"
Iron, steel and coke industry	200,000	"
Nitro-cellulose, nitroglycerine, celluloid, etc. (pre-war conditions)	150,000	"
All other industries	200,000	"
	3,250,000	"

Sulphurous Acid in the Wood Pulp Industry

One of the most important processes for manufacturing paper pulp from wood is known as the sulphite process, in which large quantities of sulphur dioxide are consumed.

The production of sulphite pulp in Canada in 1915 was 235,474 tons, as compared with 183,552 tons in 1913. The sulphur dioxide required in this industry has been obtained almost exclusively by burning elemental sulphur. In 1915, there was imported into Canada 43,432 tons of sulphur, as compared with 29,856 tons in 1914. This large and increasing supply comes mainly from Louisiana, and most is used by the pulp mills.

The use of pyrites as a source of sulphur dioxide in the pulp industry has not made headway, chiefly because of the extra space and capital required for installing the burners and dust chambers, but partly because the sulphur content is less than half the weight which has to be transported. Some manufacturers, however, use pyrites, and a description of the plant will be found in "Pyrites in Canada," by A. W. G. Wilson.[1] It may be added that an account is given by E. A. Sjostedt[2] of the plant installed by the Sault Ste. Marie Pulp and Paper Company for the production of sulphur dioxide by roasting a pyrrhotite ore; an abstract has been given by A. W. G. Wilson.[3]

In considering the possibility of employing the sulphur dioxide produced at Sudbury, it may be well to point out that there is no large amount of wood suitable for pulp making in that vicinity. From the very nature of their operations, pulp mills are forced to distribute themselves rather than to segregate, and the establishment of a large sulphite industry near Sudbury with a view to utilizing its sulphur dioxide, is unlikely. The only alternative is the shipment of the sulphur dioxide, in some form, to the pulp mills. The gas may be liquified, but this is expensive, and the handling of the liquid gas in cylinders is costly. A saturated solution of the gas in water at ordinary temperatures is weak in sulphur dioxide, and the freight would be correspondingly heavy, and the same objection holds against solution of calcium or magnesium bisulphite. For these reasons, the prospects for an outlet for sulphur dioxide in the sulphite pulp industry are unpromising.

Sodium Sulphate by the Hargreaves Process

Sodium sulphate or "salt-cake" is an important raw material in the manufacture of glass, in the dyeing industry, and in the sulphate process of making paper pulp. It, or the acid sulphate known as nitre cake, is used in the Orford nickel refining process. It was first, and is still mainly produced by the Leblanc process, by heating together salt and sulphuric acid, the hydrochloric acid gas which is evolved during the reaction being recovered in solution and sold.

The disadvantages in working the Hargreaves process are the length of time required, and the careful attention to detail which is necessary. It is worth noting, however, that gases rather poorer in sulphur dioxide than the average pyrites burner produces may be used at the expense of a longer exposure, and the signifi-

[1] Mines Branch, Department of Mines, Canada, pages 156 to 174.
[2] Jour. Canadian Mining Institute, Vol. 7, 1904, pages 480 to 494.
[3] L. c.

cance of this fact in connection with the use of gases from roasting furnaces and stacks at Sudbury is evident.

Full particulars of the Hargreaves and other processes for the manufacture of sulphate of soda have been published by George Lunge[1].

Reducing Sulphur Dioxide to Elemental Sulphur

The process of W. A. Hall depends upon the fact that when a pyritic ore is submitted to the action of a heated reducing gas mixed with steam, elemental sulphur is produced instead of sulphur dioxide, and the sulphides are converted into oxides. The roasted product is a mixture of the ordinary ferric oxide and the magnetic oxide. The reactions which take place in the furnace are not definitely known. A portion of the sulphur in the ore is merely sublimed by the heat and passes off in the elemental condition in the reducing atmosphere. Part of the remainder is oxidized by the water vapour to sulphur dioxide, and part reduced to hydrogen sulphide. These gases decompose each other, so that they also produce elemental sulphur in accordance with the well known reaction which occurs when they are mixed.

An interesting account of some large scale trials made upon the Hall process in California is given by H. F. Wierum.[2] An 18-foot 6-hearth MacDougal roasting furnace was equipped with oil burners of a special design permitting a back pressure to be maintained internally to exclude air; the lower three hearths were run under sufficient suction to permit slight oxidation.

The ore contained about 40 per cent. sulphur, and was crushed to ½ in., but better results were obtained by reducing to 10 mesh. During a week's run, the sulphur in the 10 mesh calcines averaged 5.5 per cent. with an oil consumption of 22 gallons per ton of ore, the oil costing about 3 cents per gallon. The temperature used was approximately 800° C., and the output 1 ton per hour. The maximum amount of sulphur dioxide in the gases escaping from the furnace was a trifle over 0.3 per cent. The recovery of the finely divided sulphur which issued from the furnace presented difficulties which Wierum is confident can be easily overcome. The purity of the melted-down sulphur averaged 89 per cent.

Further experimenting was stopped by the outbreak of the war, and no information is available regarding any progress which may have been recently made. The results published by Wierum are, however, promising, and are interesting in connection with the Sudbury problem. As has been mentioned on another page regarding the paper pulp industry, sulphur is imported from Louisiana into Canada to be burned to sulphur dioxide, by the pulp manufacturers, who prefer it for convenience in handling. The possibility of obtaining elemental sulphur from the roaster gases at Sudbury, is one which deserves careful consideration, and would justify the expenditure of time and money in investigating this and other processes. The Hall process is not actually in operation on a commercial scale, so far as is known to the Commission, but it may be regarded as a possible means for abating a nuisance, and assisting chemical industries.

[1] Sulphuric Acid and Alkali, 3rd Edn. V. II, part I.

[2] Mining and Metall. Soc. of America, Bull. 76, Sept. 30, 1914, Vol. 7, No. 9, pages 134-146.

The fact that it leaves a considerable proportion of sulphur in the roasted ore and that it is difficult to completely collect the finely divided sulphur produced by the process into the compact solid form of brimstone preferred by the users of sulphur, are less serious in connection with the nickel industry than appears at first sight. The primary requirement is to avoid the escape of sulphurous acid into the air. The ore is not bought as a source of sulphur, as is usually the case, and the 5 or 6 per cent. of sulphur left in the roasted ore in the trials by the company which ultimately abandoned it, possibly on that account, is less than is intentionally left in the ores roasted at Sudbury on the roast heaps, or in the Wedge roaster or the Dwight-Lloyd sintering plant.

The Thiogen Processes

These processes, which include a "wet" and "dry" process, have been described by S. W. Young.[1]

The dry process consists in passing furnace gas with a minimum of 8 per cent. sulphur dioxide over heated calcium or barium sulphide. Sulphites are formed with liberation of sulphur in the elemental form from the sulphur dioxide. The sulphites are then again reduced to sulphide by heating under reducing conditions. The temperature must be kept between 750° and 900° C. for the first reaction. Experiments on a large scale were carried out at the smelter at Campo Seco, California, but information regarding developments is lacking.

The wet process is operated with barium sulphide only, on the chemical principles outlined above, the product being a mixture of barium sulphite and sulphur, from which the latter is recovered by sublimation. So far as is known, this modification has not yet been tried on a large scale.

[1]Min. and Sci. Press, Vol. 103, 1911, page 386.
Eng. and Min. Journ., Vol. 95, 1913, page 369.

CHAPTER XII

Statistics

Even at the risk of some repetition, it has been thought advisable to present in one Chapter of the Report statistics of production of nickel in the countries which constitute the chief sources of the metal.

The following table gives the output of nickel and copper from the nickel mines of Sudbury, from the beginning to 31st December, 1916. The nickel contents of the silver-cobalt-nickel ores of the Cobalt district are not included. Although the production of nickel from 1904, when these mines were opened, to 1916, inclusive, is estimated at about 4,000 tons, only a small proportion of the nickel has actually been recovered. The ores of the Alexo mine are included, since the entire production so far has been smelted by the Mond Company at Coniston.

Nickel and Copper Production of Sudbury

Year.	Ore.		Nickel.	Copper.
	Raised.	Smelted.		
	tons.	tons.	tons.	tons.
1887–1889	(Est.) 100,000	(Est.) 80,000	(Est.) 2,400	(Est.) 2,240
1890	130,278	59,329	1,780	1,661
1891	85,790	71,840	2,155	2,012
1892	72,349	61,924	2,082	1,936
1893	64,043	63,944	1.653	1,431
1894	112,037	87,916	2,570½	2,748
1895	75,439	86,546	2,315¾	2,365⅓
1896	109,097	73,505	1,948½	1,868
1897	93,155	96,094	1,999	2,750
1898	123,920	121,924	2,783¾	4,186¾
1899	203,118	171,230	2,872	2,834
1900	216,695	211,960	3,540	3,364
1901	326,945	270,380	4,441	4,197
1902	269,538	233,388	5,945	4,066
1903	152,940	220,937	6,998	4,005
1904	203,388	102,844	4,729	2,042
1905	284,090	257,745	9,503	4,524
1906	343,814	340,159	10,776	5,260
1907	351,916	359,076	10,602	7,003
1908	409,551	360,180	9,563	7,501
1909	451,892	462,336	13,141	7,873
1910	652,392	628,947	18,636	9,630
1911	612,511	610,788	17,049	8,966
1912	737,656	725,065	22,421	11,116
1913	784,697	823,403	24,838	12,928
1914	1,000,364	947,053	22,759	14,448
1915	1,325,973	1,272,313	34,039	19,608
1916	1,572,804	1,521,689	41,299	22.430
Total.......	10,866,392	10,322,515	284,838½	175,003¼

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The figures are compiled from the annual returns of production made by the mining companies under the Mining Act of Ontario. They are based on the companies' estimate of the nickel and copper contents of the matte product of their smelters, as shipped to the refineries. Unless otherwise indicated, the ton in this Chapter and throughout the Report generally, is the statutory ton of 2,000 lbs. If the metric ton (2,204 lbs.), or the English ton (2,240 lbs.), is intended, it is so stated.

The figures show that for the first nine or ten years the growth of production at the Sudbury mines was slow, competition from New Caledonia strong, and the demand small. Beginning with 1898 there was a steady though not rapid increase; production fell in 1902, and still further in 1903. In 1904 a revival set in, and from that time down to the present, every succeeding year, with one exception, has seen a larger output than its predecessor. Thus the quantity of ore mined in 1896 to 1900 inclusive, was 82 per cent. in excess of that mined during the previous five years; 1901-1905 shows an increase over 1896-1900 of 65.8 per cent.; 1906-1910 over 1901-1905 of 78.6 per cent.; 1911-1915 over 1906-1910 of 101.9 per cent. The increase in 1916 over 1915 was 18 per cent.

Canadian Copper Company's Production

The schedule given below shows the ore production of the Canadian Copper Company's mines from the beginning to the 31st March, 1916, divided into two periods, 1887-1902 and 1903-1916, the aggregate being 7,616,447 tons. The average assay for the several mines in nickel and copper is given for both periods. It is noticeable that while the percentage of copper during the latter of the two periods is less than that of the former, the proportion of nickel is greater; and that for the entire series of years the proportion of nickel to copper is very nearly that of 2 to 1. The increased percentage of nickel in the second period is due to the dominant influence of the Creighton mine, whose ores are high in nickel and of medium tenor in copper.

Mine.	Ore raised, tons.		Total Ore.	Average Assay 1887-1902.		Average Assay 1903-1915.	
	1887-1902	1903-1915	Tons.	Ni per cent.	Cu per cent.	Ni per cent.	Cu per cent.
No. 1	23,116	336	23,452	3.55	3.42	3.21	1.13
No. 2	264,844	455,070	719,914	2.29	2.04	2.83	1.64
No. 3	106,086	178,813	284,899	2.67	1.39	1.68	1.50
No. 4	43,658	42	43,700	2.91	1.26	2.09	0.41
No. 5	8,092	....	8,092	2.84	1.06	....	....
No. 6	4,048	....	4,048	1.99	1.69	....	....
Evans	229,379	5,049	234,428	3.04	2.74	2.46	2.59
Stobie	418,991	....	418,991	2.05	1.53	....	....
Creighton	149,954	4,603,479	4,753,433	4.94	1.65	4.43	1.56
Copper Cliff	333,337	43,402	376,739	3.62	5.03	2.76	5.93
Crean Hill	....	744,747	744,747	....	....	2.14	2.91
Vermilion	....	4,014	4,014	....	....	6.64	6.89
Total	1,581,505	6,034,932	7,616,447	2.922	2.542	3.933	1.767

Average assay of ore 1887-1915, Ni., 3.724 per cent., Cu., 1.927 per cent.

Adding the production of the Canadian Copper Company's mines for the nine months, April to December inclusive, 1916, namely 904,759 tons, the total output from all of this company's properties from the beginning to 31st December, 1916, was 8,521,206 tons of ore. Based on the assay figures for the several mines, this quantity of ore contained 316,483 tons of nickel and 165,440 tons of copper. It is understood, of course, that the figures are for crude ore, and do not allow for losses in treatment.

Mond Nickel Company's Production

The production of the Mond Nickel Company's mines from the beginning to 30th September, 1915, is shown in the following figures:—

Mine	Tons ore produced	Assay per cent.	
		Ni.	Cu.
Victoria	596,934	1.9	3.4
Garson	796,011	2.3	1.9
Kirkwood...............	58,468	3.2	1.5
North Star	53,716	2.1	.8
Worthington............	74,033	3.0	3.4
Levack	27,777	2.8	.5
Little Stobie...........	1,585	....	....
Total...............	1,608,524	....	... .

Adding the production for the last quarter of 1915 and the whole of the following year, the total output of the Mond Company's mines to 31st December, 1916, was 2,027,713 tons. The total ore raised by the Alexo to the same date was 34,650 tons, all of which has been treated by the Mond Company; also 13,348 tons from Mount Nickel mine, 486 tons from the Howland, and 26,487 tons from Bruce mines. The last-named mine carries a little copper, but no nickel, and the ore is used by the Mond Company mainly as a flux. The aggregate of ore smelted was 2,065,504 tons, the product of which was 96,591 tons of matte, containing 39,006 tons of nickel and 40,125 tons of copper.

It will be seen from the preceding tables that out of the total quantity of nickel-copper ore raised in the Sudbury district, namely, 10,866,392 tons, all but 317,473 tons were from the mines of the two great producing companies, the Canadian Copper Company and the Mond Nickel Company.

New Caledonia's Output

The figures of the production of nickel in New Caledonia are drawn from a variety of sources, some of which differ among themselves, but it is believed the statistics given below are as nearly correct as possible. For the years 1875 to 1902 inclusive, the figures are taken from Glasser's Report to the Colonial Minister of France on the Mineral Wealth of New Caledonia, 1904 (p. 214); from 1903 to 1912, from The Mineral Industry, Volume XXIII (p. 933). From 1913 to 1915 they were obtained from official sources in New Caledonia itself.

Year.	Nickel Ore Exported. Metric Tons.		Value Francs.	Estimated Contents of Nickel. Metric Tons.	
1875	327		327,000	39	
1876	3,406		1,703,000	408	
1877	4,377		1,720,000	525	
1878	155		46,000	18	
1879	....		....	....	
1880	2,528		506,000	253	
1881	4,069	(5,058)	814,000	407	(506)
1882	9,025	(6,392)	1,624,000	812	(537)
1883	6,881	(6,768)	1,240,000	620	(615)
1884	10,888	(7,994)	1,578,760	871	(637)
1885	5,228	(1,095)	731,920	418	(99)
1886	921		184,200	92	
1887	8,602		1,075,000	688	
1888	6,616		827,000	530	
1889	21,000	(1,250)	2,625,000	1,680	(114)
1890	24,590	(1,900)	2,827,000	1,960	(174)
1891	54,081	(160)	5,678,000	4,326	(15)
1892	35,951		3,235,000	2,507	
1893	45,613		3,877,000	3,180	
1894	40,089		2,806,230	2,795	
1895	38,976		1,948,800	2,484	
1896	37,467		1,586,015	2,388	
1897	57,639		2,017,365	3,458	
1898	74,614		3,357,630	4,356	
1899	103,908		5,507,124	5,640	
1900	100,319		5,879,000	5,975	
1901	133,676		4,580,000	7,218	
1902	129,653		4,579,000	7,045	
1903	77,360				
1904	98,655				
1905	125,289				
1906	118,890				
1907	119,000				
1908	108,000				
1909	86,000	Matte			
1910	99,000	768			
1911	142,000	2,993			
1912	74,314	5,908			
1913	93,190	5,893			
1914	94,154	5,277			
1915	48,576	5,529			
Total	2,245,354		....	....	

An examination of the figures in the foregoing table shows that the ores exported at the beginning were very rich, running up to 12 per cent. of nickel, but that there was a steady fall in the grade from 1880 on. In 1880 and 1881 the ores averaged ten per cent. nickel; in 1882 and 1883, nine per cent.; from 1884 to 1891, eight per cent.; from 1892 to 1894, seven per cent.; and in 1902 and for several years previous it was 5.4 per cent. These percentages are deduced from M. Glasser's figures.

The ore shipped from 1903 to 1915 inclusive was 1,284,428 tons, and assuming there has been no reduction since 1902 in the grade of ore exported, this quantity at 5.4 per cent. would contain 69,359 tons of nickel. In addition, during the last six years covered by the table, 26,368 tons of matte were exported. At the ordinary grade, 45 per cent. nickel, the matte would contain 11,866 tons of nickel. The total quantity of nickel sent out from New Caledonia up to 31st

December, 1915, whether in form of ore or matte, would therefore appear to be as follows:—

	Metric tons.
1875-1902	60,693
1903-1915 (in ore)	69,359
do do (in matte)	11,866
Total	141,918 tons.

This is equal to 156,394 tons of 2,000 lbs.

The figures in parentheses in Glasser's table refer to the ore smelted on the Island, but that writer explains that his statistics are compiled on the assumption that all the exports were of crude ore, and would therefore include the matte.[1]

A comparison of the tables shows that of recent years the production of Ontario has been growing much more rapidly than that of New Caledonia. Figures for the last three five-year periods bring this out very clearly:—

	New Caledonia. Metric tons.	Ontario. Tons of 2,000 lbs.
1901-1905	30,490	31,616
1906-1910	29,014	62,718
1911-1915	35,941	121,106
Total	95,445	215,434

Converting metric tons into tons of 2,000 lbs., the output of New Caledonia for the three periods mentioned was 33,600, 31,973 and 39,607 tons respectively. It is thus seen that during the first of these periods the output of New Caledonia exceeded that of Ontario by six per cent.; in the second, the New Caledonia production slightly receded, while that of Ontario almost doubled, and was practically twice the yield of New Caledonia. In the third period, while New Caledonia showed a growth of 24 per cent., Ontario again produced almost twice as much as in the preceding period, and more than three times the output of the French colony.

It should not be overlooked, however, that while Ontario's production is increasing, so also is that of New Caledonia. This fact of itself argues an innate vitality in the nickel industry of Ontario's chief competitor.

Norway

Norway is another country which at the present time is producing nickel on a considerable scale from ores worked for that metal, though its output cannot be compared with that of either New Caledonia or Ontario, and is probably less than the "by-product" nickel now obtained, chiefly in the electrolytic refining of copper. By-product nickel is discussed in Chapter IX of the Report, and its chief sources pointed out. Nickel mining is an industry of old standing in Norway, but the ores,

[1] The ore shipped from New Caledonia contains at least 20 per cent. of moisture. The assay is always given for dried ore, so that 8 per cent. ore would contain 6.4 per cent nickel in the wet state; 7 per cent. ore would contain 5.6 per cent. nickel, and 6 per cent. ore 4.8 per cent. nickel. M. Glasser remarks that for certain of the years covered by his statistics, the figures of value seem to have been obtained by multiplying the tonnage of wet ore by the value of a ton of dry ore, and that they should, therefore, be reduced about 25 per cent. In assuming that the ore since 1902 contained as shipped, i.e., in the natural moist condition, 5.4 per cent. of nickel, the case is probably put too favourably for New Caledonia. During recent years, the exported ore has carried on an average 6 per cent. nickel when dried, or say 4.8 per cent. as shipped.

while similar in character to those of Sudbury, are poorer in both nickel and copper. The industry was in a languishing condition for some time previous to the establishment of a refinery at Kristianssands, to operate the Hybinette electrolytic process, which has been producing refined nickel and copper for several years. Part of the ore treated at this plant comes from other countries, such as Greece and Tasmania, but the chief sources of supply are the Norwegian mines. The Swedish mines are small, and do not appear at present to be in operation.

The following figures showing the production of nickel ore and nickel in Norway, are taken for the years 1901 to 1912 from The Mineral Industry (1914), p. 958, and for 1913 to 1915 were obtained in Norway itself.

Nickel Production of Norway

Year.	Ore Metric Tons	Nickel Metric Tons
1901	2,018	13
1902	4,040	40
1903	5,670	60
1904	5,352	75
1905	5,477	73
1906	6,081	77
1907	5,781	81
1908	5,190	81
1909	5,770	62
1910	19,639	69.8
1911	27,743	172
1912	30,697	390
1913	46,750[1]	602
1914	49,854[2]	841
1915	....	793

[1] Including about 3,250 tons imported.
[2] Including 2,000 tons from Greece.

The above statistics are of special interest at this time, not because they represent a large production, but from the fact that during the present conflict, the nickel product of the Kristianssands refinery has been going to Germany.

Germany

The nickel mines of Germany herself are neither large nor productive. The following figures, taken from The Mineral Industry, Volume XXIII (1914), page 941, show the annual output of ore from 1902-1913, the average content of which is given at about two per cent. The production seems to be entirely from Prussia.

Year.	Metric Tons.	Year.	Metric Tons.
1902	11,816	1908	8,238
1903	14,058	1909	10,095
1904	13,518	1910	10,053
1905	10,432	1911	9,609
1906	7,472	1912	12,091
1907	7,557	1913	13,538

It would thus appear that the total output of nickel ore in Germany during the twelve years 1902-1913, was 128,496 metric tons, or 141,603 tons of 2,000 lbs. If the ore contained two per cent. nickel the whole contents of metallic nickel would be 2,832 tons. No figures of production have been published since the war began, but it is in every way likely that the nickel mines of Germany have been and are now being worked more extensively than before that time, and a larger output obtained. Germany, however, in pre-war times, did not depend upon her own rather meagre resources, or those of the rest of Europe, for her supplies of nickel. She was a large importer and refiner of New Caledonia ore, and a large seller of refined nickel.

The production of refined nickel in Germany has considerably increased of late years. As given by the tables of the Metallgesellschaft, the output of refined nickel for that country, as well as for France, England, United States and Canada, and "other countries" from 1896 to 1912 was as follows in metric tons:—

World's Production of Refined Nickel

Year	Germany	France	England	United States and Canada	Other Countries	Total
1896	822	1,545	340	1,700	....	4,407
1897	898	1,245	715	1,900	....	4,758
1898	1,108	1,540	1,000	3,250	....	6,898
1899	1,115	1,740	1,350	3,650	....	7,855
1900	1,376	1,700	1,450	3,000	....	7,526
1901	1,700	1,800	1,800	3,600	....	8,900
1902	1,600	1,100	1,300	4,700	....	8,700
1903	1,600	1,500	1,700	5,100	....	9,900
1904	2,000	1,800	2,200	6,000	....	12,000
1905	2,700	2,200	3,100	4,500	....	12,500
1906	2,800	1,800	3,200	6,500	....	14,300
1907	2,600	1,800	3,200	6,500	....	14,100
1908	3,000	1,400	3,000	7,000	200	14,600
1909	3,500	1,200	3,200	9,000	400	17,300
1910	4,500	1,500	3,500	10,000	600	20,100
1911	5,000	2,000	4,500	12,000	1,000	24,500
1912	5,000	2,100	5,200	15,000	1,200	28,500
1913	....	....	....	....	....	30,000
Total	41,319	27,970	40,755	103,400	3,400	246,844

The total output from all the above countries in 1913 is given as 30,000 metric tons, making an aggregate, according to this authority, from 1896 to 1913 of 246,844 metric tons, equal to 272,022 tons of 2,000 pounds. The nickel refined in Germany and France was very largely from New Caledonia ore and matte; that in England almost wholly from New Caledonia ore and matte until 1901, and afterwards from Ontario matte as well; in the United States and Canada, well-nigh altogether from Ontario matte. Comparing Metallgesellschaft's statistics with those given on pages 495 and 498, it is found that the latter show New Caledonia during the same period to have exported 104,535 metric tons of nickel in ore and matte, and Ontario 155,884 metric tons, a total of 260,419 metric tons. Allowing "other countries" the 3,400 tons ascribed to them, the excess over Metallgesellschaft's figures is about 6 per cent., a difference easily accounted for by losses in refining. The heading "United States and Canada" is misleading, as the table purports to show the country in which the nickel was refined, and during the period it covers no nickel was refined in Canada.

United States Imports of Nickel

The following statistics regarding nickel entering the United States in the form of matte and ore are taken from the yearly and monthly statements of the U. S. Bureau of Foreign and Domestic Commerce, and from its annual volumes entitled "Commerce and Navigation of the United States." The amount of nickel present appears to have been calculated from the figures supplied by the shippers, as is usual when the material referred to enters duty free.

In all these tables the English ton of 2,240 lbs. is used unless specially indicated. For these notes, the figures have been recalculated to the ton of 2,000 lbs. to prevent confusion.

It is not possible to exactly compare the U. S. figures with those published by the Ontario Bureau of Mines, or given by the Canadian Copper Company, as the years are made up to different periods, but it is reasonable to think that the three-year period taken for each will be near enough for all practical purposes.

Separate statistics of the imports of matte and of ore other than from Sudbury, are not available. The figures published are for "ore and matte." It is evident from the figures given in tables A and B, that very little ore goes to the United States, and it should be noted that, whereas in 1914, only 3.36 tons of matte came from Norway, no less than 409.9 tons, containing 64.6 per cent. nickel, entered in 1915, although apparently none was sent in 1916.

The U. S. statistics give certain figures as to imports of nickel as metal and alloys and oxide, etc. They are small in the aggregate (valued only at about $20,000 in 1915) and the figures do not discriminate between the different forms in which the nickel is imported.

Table A

Matte and ore imported into the U. S. during three years ending June 30th, 1916.

Year.	From all sources.		Per cent.	From Ontario.		Per cent.
	Weight.	Nickel contents.		Weight.	Nickel contents.	
	tons	tons		tons	tons	
1914............	40,790	21,766	53.4	39,394.9	20,753.6	52.7
1915............	34,457	18,997	55.0	33.143.0	18,303.6	55.2
1916............	63,805	34,507	54.1	59,071.0	32,311.1	54.7
Total.........	139,052	75,270	Av. 54.1	131,608.9	71,368.3	Av. 54.2

Matte produced by the Canadian Copper Company during three years ending March 31st, 1916.

Year.	Weight.	Nickel contents.	Per cent.
	tons	tons	
1914............	40,267	21,702	53.9
1915............	31,428	16,866	53.7
1916............	56,405	30,181	53.5
Total.........	128,100	68,749	53.7

By deducting from the above U. S. figures, the imports during the three months ending June 30th, 1916, and adding one quarter of the imports during 1914, we obtain what may be taken as the imports for three years to March 31st, 1916, to compare with the above figures showing the matte production of the Canadian Copper Company during that period, all of which was exported to the United States. The imports for the three years, therefore, appear to have been 132,910.4 tons matte and ore containing 71,648 tons nickel metal, i.e., 53.9 per cent. nickel.

Table B

Imports of "nickel ore and matte" from countries other than Ontario, for the three years ending June 30th, 1916.

Country.	1914			1915			1916		
	Nickel contents. Ore and Matte.			Nickel contents. Ore and Matte.			Nickel contents. Ore and Matte.		
	tons	tons	per cent.	tons	tons	per cent.	tons	tons	per cent.
Belgium...........	1,392	1,019	73.2	271.0	159	58.6	....	....	......
Norway...........	3.36	2.5	74.3	409.9	265	64.6	....	....	......
Oceania...........	....	....	......	673.1	270	40.0	....	....	......
France	....	....	......	....	....	......	332.6	257.4	77.15
Australia	....	....	......	....	....	......	1,488.5	634.0	42.60
French Oceania....	....	....	......	....	....	......	2,932.2	1,196.0	40.79
Peru	....	....	......	....	....	......	1.12	.059	5.27
Total......	1,395.36	1,021.5	73.2 Av.	1,354.0	694	51.2 Av.	4,754.42	2,087.5	43.91 Av.

As indicated by the above table, the matte and ore imported into the United States from elsewhere than Ontario during the three years July 1st, 1913, to June 30th, 1916, totalled 7,504 tons, containing 3,803 tons metallic nickel, i.e., an average of 50.68 per cent. This is a small quantity in comparison with the total, but is very large as a factor regarding supplies of the metal other than from Canada. In 1916 it totalled 4,754 tons, containing 2,087 tons of nickel, i.e., about 43.91 per cent.

The New Caledonia material (probably all that given under Oceania, etc.) was practically all matte. The unbessemerized matte would no doubt contain between 40 and 45 per cent. of nickel. It was formerly bessemerized in Belgium, but since the war began has gone to France and Great Britain, with the above small but increasing quantity to the United States.

In 1913, Belgium sent about 130 tons more than in 1914; Norway and New Caledonia are not quoted as sending anything in 1913, and the published statistics indicate that Norway sent nothing in 1916.

The Monthly Summary of Foreign Commerce for the United States for December, 1916, gives the imports of nickel matte and ore during the three years 1914 to 1916, ending December 31st. They are quoted below, together with the weights of metallic nickel stated to be contained, and with the percentages of nickel calculated from such figures. The exports of nickel matte from Canada to the United States during the same period and the percentage of nickel in it have been added to the table. The figures show practically the same percentage of nickel in the total imports as the average for the Canadian matte imported, and confirm other published U. S. statistics which indicate that little or no nickel ore is imported into the States, also that the matte obtained from sources other than Sudbury (i.e., other than from the Canadian Copper Company) averages about the same percentage of nickel as the latter.

Table C

U. S. imports of matte and ore during three years ending December 31st, 1916.

—	Total matte and ore from all sources. Years ending December 31st.			Total matte from Canadian Copper Company Years ending December 31st.		
	1914	1915	1916	1914	1915	1916
Matte and ore, tons........	33,111.7	51,293.8	66,909.9	32,570	49,828	63,567
Nickel in ditto, tons........	17,503.4	28,176.3	36,305.7	17,187	26,786	34,847
Per cent. nickel in ditto	52.86	54.93	54.26	52.77	53.76	54.82

NOTE—Matte only is exported by the Canadian Copper Company.

United States Exports of Nickel

The following table showing nickel exports from the United States is taken from "Foreign Commerce and Navigation of the United States" for the year ending June 30th, 1915, pp. 624-25.

Table D

Exports of nickel, nickel oxide, and matte from the United States.
Years ending June 30th.

———	1913		1914		1915	
	Lbs.	$	Lbs.	$	Lbs.	$
Austria-Hungary	134,400	51,800	672,043	259,100	67,200	26,000
Belgium	1,719,285	666,108	1,230,274	475,175	210,612	79,400
Denmark	....	....	....	....	43,830	17,532
France	4,197,110	1,577,500	4,419,663	1,583,830	3,210,980	1,168,022
Germany	2,346,325	441,447	11,081,366	3,007,786	1,036,242	280,100
Italy	1,075,303	414,100	1,276,905	446,900	2,365,177	970,617
Netherlands	9,164,012	2,812,300	2,376,216	840,269	22,033	8,813
Norway	....	....	....	....	31,158	10,147
Russia in Europe	7,250	2,800	186,626	72,000	4,082,280	1,771,880
Spain	....	....	....	....	700	300
Sweden	....	....	....	....	367,696	168,426
England	2,334,845	651,500	2,171,511	619,300	8,535.418	2,932,359
Scotland	6,878,264	2,649,000	5,433,081	2,082,700	7,817,384	2,946,360
Canada	16,379	6,204	42,529	16,112	52,949	19,223
Mexico	....	....	....	....	1,779	751
West Indies	....	....	....	....	300	148
Brazil	1,796	712	....	....	....	....
Columbia	32	13	....	....	....	....
Japan	5,447	1,913	2,028	537	308,444	131,465
Russia in Asia	....	....	....	....	1,423,030	569,020
Oceania	829	317	....	....	22,400	10,136
Total	27,881,277	9,275,714	28,895,242	9,403,709	29,599,612	11,110,699

Statistics of export are also given for the calendar years 1915 and 1916, in the "Monthly Summary of Foreign Commerce of the United States" for December. 1916. p. 47. They are here reproduced:—

Exports of nickel, nickel oxide, and matte from the United States.
Years ending December 31st

Country	1915		1916	
	Lbs.	$	Lbs.	$
France	3,018,354	1,124,382	2,823,132	1,101,813
Italy	....	....	2,715,521	1,110,035
Netherlands	129,557	55,954	516,331	224,872
Russia in Europe	....	....	7,767,875	3,010.599
United Kingdom	14,801,565	5,317,532	16,674,487	6,191,029
Other Countries	8,469,074	3,630,646	2,906,665	1,314,145

CHAPTER XIII

Taxation of Mines and Mining Industries

The Commissioners were instructed to inquire into and report upon such matters as in their opinion will assist the government "to provide a system of taxation upon mines, mining land, claims or rights, minerals and industries connected with mining, that will be just and equitable and in the best interests of the Province." They have given the subject careful consideration, and have made inquiry into the operation of the laws at present in force in Ontario, and into the nature and results of different systems of mining taxation, particularly in English-speaking countries. They have found a great variety of methods.

In the United States

In many States of the Union, for instance, mines, mineral deposits and mining plants are assessed and taxed in the same way as other tangible property. In a few States a tax is levied on the gross annual receipts, and in a few others on the net annual receipts. In one or two cases, depending upon some peculiar local conditions, a hybrid system has been adopted, by which the gross receipts and the net receipts of operating mines are combined in arbitrary proportions as the basis of taxation. In all the States one tax is levied for State, county and local purposes, the tax being collected as a whole, and afterwards distributed to the several authorities. Usually the law requires all property, including mines, to be assessed at its full value, but in a number of States, the standard of assessment varies from 20 per cent. to 80 per cent. of the value.

The following States depart from the prevailing method and assess mines on the basis mentioned; Arizona, the full cash value of four times the net receipts, plus 12½ per cent. of the gross receipts; Colorado, one-fourth of the gross proceeds, or net proceeds if in excess of one-fourth of the gross proceeds; Idaho and Montana, the price paid the government for the land plus the net proceeds; Nevada, net proceeds at 80 per cent. of their actual value; Wyoming and South Carolina, gross proceeds; Utah, net annual earnings. On the assessment so made, the mines pay taxes at the general rate imposed on other tangible property in the local subdivision of the State in which they are situated. In Oklahoma a State tax is levied of one-half of one per cent. on metallic products and three per cent. on the value of petroleum and natural gas. Coal mines in Pennsylvania, in addition to ordinary taxation on the land, pay two and one-half per cent. on the market value of the product.

The system of taxation is a matter governed by the State constitution, and State constitutions are difficult to change, requiring not only action by the Legislature, but a vote of the people. In California, Utah and Arizona, all important mining States, an agitation is at present on foot for amendment of the taxing laws as regards mining.

In Other Countries

In other countries a similar variety prevails. In Spain the tenure of minerals is conditioned on the payment of a specified tax to the government, and this custom has spread to practically all countries of Spanish origin. In Mexico, for instance, mining lands are held on payment of a tax per mining area (pertinencia, = 2.47 acres), payable to the central government. This tax was formerly at the rate of $2.50 per pertinencia, but recently has been greatly increased by the Carranza government, now nominally in power. In New Caledonia, Ontario's competitor in the nickel industry, a tax of five per cent. ad valorem is imposed on all nickel or other ore exported, on a valuation made by the government. Two such valuations were made in 1916, one at the beginning of each half year. The second valuation, as regards nickel ore, was much higher than the first. Export duties on matte were abolished in 1913, with the view of promoting the treatment of the ore within the colony. There is also a surface tax, varying from 75 centimes to four francs per hectare (31.25 cents per acre), the tax per hectare rising with the area of land held.

Nor is there any uniformity in the methods of taxation employed in the several parts of the British Empire. In England itself, mining lands are liable to land tax, succession duty, poor rates and local charges, also to income tax, which is essentially a tax on profits. No allowance is made for capital invested, or for exhaustion of the mines.

In the Canadian Provinces

The principal mining Provinces in Canada are Ontario, British Columbia, Alberta, Nova Scotia, and Quebec, also the Yukon district. In Ontario mines are taxed on their net profits, the law being more fully explained on subsequent pages. In British Columbia there is a tax of 10 cents per ton on coal; other mines pay two per cent. of the value of the ore raised. There is also a tax of 25 cents per acre on unworked mining lands. In Alberta coal is mined under the Dominion regulations, which require payment of rental at the rate of one dollar per acre per annum and a royalty of five cents per ton. In Nova Scotia the tax on coal is 12½ cents per ton, and royalties are levied on the gross value of other minerals as follows: Gold, silver and tungsten, two per cent.; copper, four cents per unit (or one per cent.) per ton of 2,352 lbs. of copper ore; lead, two cents per unit; and iron ore, five cents per ton of 2,240 lbs. In Quebec the Lieutenant-Governor in Council is authorized—but not until five years from the sale of the lands by the Crown—to levy a royalty, "if he thinks proper," not exceeding three per cent. of the value of the minerals extracted, after deducting costs of extraction. In the case of asbestos, one of the chief minerals of the Province, the cost of treating the rock is also deducted. Mineral lands are assessed for taxation without regard to the increased value caused by the existence of mines and minerals. In the Yukon, the regulations made in 1898, when the gold fields began to be worked, imposed a royalty of 10 per cent. on the gold obtained. This was afterwards reduced to two and one-half per cent. The total value of the gold recovered up to 31st December, 1915, was $162,231,607, on which a royalty of $4,356,180.10 was collected, an average of 2.685 per cent.

Australia and South Africa

In the several States of the Australian commonwealth, there is a nearer approach to uniformity, yet differences exist. There is in Australia a preference for the leasing system as against freehold grants, consequently mining lands, as a rule, are paid for by annual rental. In Victoria, gold-bearing lands are leased at 2s. 6d. per acre; other minerals, including coal, from 1s. to £1 per acre. There are no royalties. In New South Wales, the rent of gold and other mineral lands, save coal, is 2s. 6d. per acre, with a royalty of one per cent. on the gross value of the gold and other minerals recovered. The royalty on coal is 3d. to 6d. per ton. In South Australia, lands containing gold and other minerals rent for 1s. per acre. A tax of two and one-half per cent. is payable on the net profits. Queensland collects rent at the rate of £1 per acre for gold-bearing lands, 6d. per acre for coal lands, and 10s. per acre for lands containing other minerals. Coal pays a royalty of 3d. per ton for the first ten years and 6d. per ton afterwards. Gold and other minerals pay no royalty. In West Australia the rent of gold lands is 5s. per acre for the first year, and thereafter £1; of coal lands, 6d. per acre, with a royalty of 3d. per ton for the first ten years, and thereafter 6d. per ton; and all lands containing other minerals, from 2s. to 5s. per acre. There is a royalty of 1s. per ounce on gold. Tasmania rents her gold lands at £1 per acre, coal lands at 2s. per acre, and lands carrying other minerals, 5s. per acre. No royalties are imposed. In the Australian States the income tax is freely used, and mining, as well as other companies, pay tax on income, allowance being made for the vanishing character of mining assets. In Queensland, costs actually incurred by mining companies up to the time of declaring the first dividend, are allowed to be amortized. In New Zealand, the rental of gold-bearing lands is 7s. 6d per acre; coal, 1s. to 5s. per acre; other minerals, 2s. 6d. Gold pays a royalty of 2s. per ounce; coal 2d. to 1s. per ton; other minerals, one to four per cent. of their value.

In the Union of South Africa the profit method of taxation obtains. The tax on the profits of mining for gold is 10 per cent. and on the profits of mining for other minerals on a sliding scale, rising from two and one-half per cent. to six per cent. and upwards, according to the proportion which the amount of profit bears to the gross revenue. Gold mines also pay a rental of £1 per month for each mining claim, of about 2.1 acres. Mines are not assessable by the local municipality, and there is no taxation on income, or on the contents of the mine or mining plant. An allowance is made for amortization of capital actually put into the mine. The gold mining companies of the Transvaal pay about £1,000,000 in taxes per annum. Diamonds form an exception, the government claiming a partnership in all diamond mines. In the Transvaal the government is a partner to the extent of 60 per cent.; in Orange Free State to the extent of 40 per cent., and in Cape Colony 50 per cent. The profits, which are very considerable, are divided in the foregoing proportions. The De Beers mine, however, pays only 10 per cent. At present the Transvaal mines are paying also £500,000 per annum as a war tax, which is levied on the companies in proportion to their profits. It should not be overlooked that the chief industry of the Transvaal consists in the gold mines of the Rand, which produce annually about 40 per cent. of the world's output of gold. In 1913 the mineral exports of South Africa formed 77.8 per cent. of the total exports.

The foregoing examples show that methods vary according to local conditions, out of which occasionally arise provisions not readily intelligible at a distance. The practice by which farmers or others who own the land have leased the rights on a royalty basis is the explanation of some of them; others are the result of compromise between contending interests, or the exercise of some powerful influence. Other purposes are frequently had in view besides the collection of revenue, and the method adopted, or the rate imposed, will be found to depend largely upon the special conditions and requirements of the community.

Position of Ontario's Mining Industry

Upon any accepted theory of taxation, the mining industry should contribute its fair proportion to the revenues of the Province and the local district. Mine-owners enjoy the benefits which a stable government affords, and the resources of the State are at their disposal for protection and redress. Their ownership of remunerative properties insures their capacity to pay. Possessing what may prove to be a valuable part of the public domain, they should return a reasonable portion of the proceeds towards the maintenance of the State. The mining industry, however, is exceptional in some respects, in regard to taxation. There is in the first place a fundamental difference between a mine and land used for agricultural or building purposes, or the great majority of industrial properties, in that the use of a mine naturally involves its exhaustion. In Ontario the mining districts are mostly situated in new and remote sections of the Province. The mine owners are often obliged to provide practically all the ordinary requirements in the way of roads, telephones, housing accommodation, municipal organization, and the innumerable advantages of a settled community, which other industries elsewhere find at hand.

These conditions are accepted in the hope of eventually obtaining a fully compensating return, and are inevitable in the case of an industry of any kind established in such a region. In one important respect, the mining industry of Ontario has enjoyed an unusual advantage. In many countries heavy charges on the carriage of ore and supplies are incurred, because of distance from railway communications. Here, the Canadian Pacific, the Timiskaming and Northern Ontario, the Canadian Northern and the National Transcontinental, all government-aided, or government-owned railways, have either preceded or accompanied the mining industry into almost every area in which it is flourishing to-day.

There is no disposition on the part of the mining companies to evade a fair share of the burden of taxation. Their representations to the Commission have been addressed entirely to the question of the best and fairest system, in comparison with other industries and taxable properties. In regard to the special burdens arising from the war, they have volunteered their anxiety to contribute generously with the rest of the Province.

It should be pointed out, too, that the mining industry is one of the most effectual agencies in the settlement of our northern and northwestern districts. It affords employment to labour, frequently on a large scale, and provides the best kind of market for farm produce and manufactured goods. Not only the tillers of the soil, but the artisans and merchants of the older parts of the Province derive

a benefit from the increase in business arising out of the mining industry. That this benefit is large, may be judged from the fact that on a close estimate it takes ten million dollars to pay the wages and provide the supplies for the Sudbury nickel mines for twelve months. The railway companies also feel the effects in a larger volume of business. The Timiskaming and Northern Ontario railway found its largest source of revenue in the passenger and freight business of the Cobalt and Porcupine camps, especially while coal was still coming in large quantities, for the production of power, and Sudbury, Copper Cliff and Coniston are among the heaviest revenue stations of the Canadian Pacific railway in Ontario.

Mining taxes in general may be classified according to their basis, on (1) acreage, (2) tonnage or output, (3) the value of the mine, (4) profits.

In some cases more than one kind of taxation is employed; for instance, an acreage tax may be levied as well as a tonnage or profit tax. In addition to the main tax on net profits, both the acreage and output taxes are used to a limited extent in Ontario, and petroleum rights severed from the land are assessable at their actual value. Before examining the comparative merits of these several systems, it is advisable to state shortly the law at present in force in this Province.

The Ontario Mining Tax Act

By the British North America Act (sec. 92, s.s. 2), the Province has plenary power to impose " direct taxation within the Province in order to the raising of a revenue for Provincial purposes," and also to raise a revenue for Provincial, local or municipal purposes by means of licenses.

Both before and since Confederation, a royalty on ores taken from lands granted by the Crown has been imposed at various times; but it has been as often revoked. The last occasion was in 1891 when the Mining Act was amended by reserving to the Province a royalty on ores found on lands thereafter granted. This was repealed in 1900. No revenue ever accrued under any of these royalty provisions, and the mining industry contributed nothing whatever to Provincial revenue by way of taxation until 1907. Mining properties were taxable for local or municipal purposes only. Mineral lands and the buildings thereon were assessable at the value of other lands in the neighbourhood for agricultural purposes, but the income derived from any mine or mineral work was subject to taxation by the municipality in the same manner as other incomes under the Assessment Act. It may be doubted whether any municipality ever received any revenue from this provision.

By the Supplementary Revenue Act, 1907, now The Mining Tax Act (R.S.O., 1914, cap. 26), the present system of taxation on the net profits was adopted. and it was provided that three per cent. of the annual profits, as ascertained and fixed under the Act, in excess of $10,000, should be paid each year to the Provincial Treasurer for the use of the Province. The Act contains well considered provisions for determining the amount of the annual profits for taxation by specified deductions, and provides the required machinery for its enforcement and operation.

For a full understanding of the taxation of mines in Ontario it is necessary to consult also the Assessment Act (R.S.O., 1914, cap. 195), which provides that

subject to the prescribed and usual exemptions (sec. 5), "all real property in Ontario, and all income derived either within or out of Ontario by any person resident therein, or received in Ontario by or on behalf of any person resident out of the same, shall be liable to taxation." Every person occupying or using land for the purpose of any of the businesses specified in the Act, shall be assessed for a "business assessment" to be computed by reference to the assessed value of the land so occupied or used by him (ibid., sec. 18). The business of mining or treating ores is not specified, and is consequently exempt from business assessment. Every person not liable to business assessment shall be assessed in respect of income; and every person liable to business assessment shall be assessed in respect of the income derived from his business to the extent to which it exceeds the amount of his business assessment (ibid., sec. 11).

By section 40, s.s. 4, the buildings, plant and machinery in, on or under mineral land and used mainly for obtaining minerals from the ground or storing the same, and concentrators and sampling plant and the minerals in or under such land are declared not assessable. In no case shall mineral land be assessed at less than the value of other land in the neighbourhood used exclusively for agricultural purposes (ibid., s.s. 5). The income from a mine or mineral work shall be assessed by, and the tax leviable thereon shall be paid to, the municipality in which such mine or mineral work is situate (ibid., s.s. 6). Sub-section 9 is as follows:—

(9) Notwithstanding anything in this section contained, no income tax shall be payable to any municipality upon a mine or mineral work liable to taxation under section 5 of The Mining Tax Act, in excess of one-half, in the case of the town of Cobalt as at present constituted, and in excess of one-third, in the case of all other municipalities, of the tax payable in respect of annual profits from such mine or mineral work under the provisions of the said section and amendments thereto.

This sub-section must be read with section 14 of *The Mining Tax Act,* whereby the mine-owner is entitled to deduct to this extent the amount of the municipal income tax from the amount payable to the Province. The sections are a little cumbrous, but in practice the municipality invariably receives its maximum share of the tax, and the receipt of the municipality is accepted by the Mine Assessor for the amount.

Assuming that the profits of a given mining company for the year 1915 are \$210,000; the first \$10,000 being exempt, the three per cent. tax is levied on \$200,000. Consequently, in 1916 the mine will contribute in taxation \$6,000 in all, of which \$2,000 will go to the municipality, and \$4,000 to the Province. The net result of the law is that, with the unimportant exceptions of the acreage and output taxes mentioned below, the sole tax on mines and mineral deposits in this Province is three per cent. on the net annual profits of operating mines above \$10,000, of which in practice two per cent. is received by the Province, and one per cent. by the municipality.

An annual acreage tax of two cents per acre is imposed on all patented or leased mining lands in unorganized territory of the Province (Mining Tax Act, sec. 15, s.s. 1). Where municipal organization has been effected this acreage tax does not apply. Land in bona fide use or reasonably required for farming purposes, or occupied by buildings, is exempt (ibid., s.s. 2). One-half of the amount actually received

by the Province from this source is paid to the trustees of school sections in such territory for school purposes. This tax took the place of the so-called Algoma Land Tax of one cent per acre, which was levied on all lands granted in the north-western districts of the Province. The total receipts from 1907 to 1916 inclusive from the acreage tax, have been $118,277.30, an average of $11,827.73 per annum.

Another feature of the Mining Tax Act is the imposition of two cents per thousand cubic feet on natural gas. The Act provides for a rebate of 90 per cent. in the case of gas used in Canada. The net rate, therefore, is two-tenths of one cent per thousand cubic feet. The total collected under this provision for the ten years has been $189,920.66, or at the rate of $18,992.06 per annum.

Taxation on Acreage

Reverting to the general subject of mining taxation, it may be said that an acreage tax possesses the merit of simplicity, and has little else to commend it for other than secondary purposes. In the case of Ontario it is unimportant and was, presumably, not primarily designed for the production of revenue. It takes no account of the varying value of mining lands. A piece of swamp or barren rock, patented under the Mining Act, pays at the same rate as the richest nickel or gold mine, and the system is, accordingly, wanting in the first essentials of scientific taxation. An attempt to collect a substantial revenue by an acreage tax on the patented mining lands of Ontario would be hopeless. To tax unproductive and unpromising mining lands at a high rate would result in their forfeiture, and the operation might be repeated indefinitely with little advantage to the revenue.

The acreage tax, however, serves useful purposes in this Province. In default of payment for two years, the lands may be forfeited to the Crown, and again opened for location under the Mining Act. Probably 200,000 acres of land have already thus been forfeited. The procedure clears the title, which is important, since a tangled title effectually deters investment of capital. In some of the mining districts there are many acres of good agricultural lands held under the Mining Act, now lying idle and untilled, with an excellent market for produce close at hand. It is possible that a substantial acreage tax would promote the use and cultivation of such lands, and assist in providing a local supply of farm products for the mining camps.

It is the opinion of the Commissioners that the present rate of the acreage tax is much too low. It is not high enough for revenue, and not so effective for the achievement of secondary purposes as a higher rate would be. If substantially increased, it would exert pressure upon owners of undeveloped mining lands to examine them for deposits, which, if found promising, would doubtless be worked. The chances of the land lying entirely idle would be reduced; the prospects of forfeiture to the Crown would be increased; and there is always the possibility that in more skilful or diligent hands better results would be obtained. It is clearly in the public interest that prospecting and search for minerals should be stimulated and maintained, and that unworked lands should be available to the prospector.

One-half the amount collected under this tax within the limits of a school section, is payable to the school trustees. The Commissioners see no reason why this provision should not be continued. Anything that tends to bring the benefits of education within the reach of the small communities which spring up in the new districts of Ontario, is worthy of encouragement.

It may be added that there is no provision in the Assessment Act for the assessment of mineral rights that have been severed from the surface rights, save in the single case of petroleum (section 40, s.s. 8), consequently mineral rights so severed escape municipal taxation. Section 15, s.s. 1, of the Mining Tax Act, subjects them to the 2-cent. per acre tax for Provincial purposes, but only when situate in unorganized territory. It is a fact that in the counties of southeastern Ontario thousands of acres have passed from previous to subsequent owners "reserving the mining rights." The holders of these mining rights pay no taxation of any kind. This anomaly could be removed by making mineral rights held separately from the surface, in organized as well as unorganized territory, liable to the acreage tax under the Mining Tax Act. The proceeds might be divided equally between the Province and the municipality.

Taxation on Tonnage or Output

The tonnage or output tax has also the desirable attributes of being both definite and simple. As applied to homogeneous substances, such as natural gas, it is convenient and practicable, but as a general mining tax it is clearly inequitable and unsuited to the mining conditions of the Province. Like the acreage tax, it disregards both values and profits. The tax on a ton of gold ore barely good enough for milling will be as much as on a ton of the richest quartz. It may even turn the scale between profit and loss, and condemn to idleness a property which, under a different system, might have had a fair chance for successful operation. An output tax discourages development, and bears most heavily in the early stages of production, or in a later stage when production is falling off. It would be a constant source of complaint from owners whose operations it burdened, and the grievance would be aggravated by the knowledge that their competitors with richer ores and more productive properties paid no heavier rate.

The tax on natural gas, with the rebate, has eliminated the wanton waste of natural gas which was common in the gas-fields of Ontario, as in gas-fields in other parts of the world. The gas allowed to escape is not "used" within the meaning of the Act, and consequently is taxable at the full rate of two cents per thousand cubic feet. The pressure of the larger impost has been sufficient to induce gas well proprietors to stop the leaks and earn the rebate. The cost of maintaining inspectors in the gas-fields to check waste and see that abandoned wells are properly plugged, is fully met by the proceeds of the tax, and in the opinion of the Commissioners, it would be in the public interest to continue the tax on natural gas.

Taxation on Mine Valuation

The ad valorem system, whereby mines and all mineral deposits are assessed for taxation on the basis of their value as determined by the taxing authorities, is in force in some of the leading mining States of the Union; and it is the only

form of mining taxation which offers any real competition with the taxation of net profits, which has been adopted in Ontario. Its prevalence in the United States is not the result of deliberate choice, or of a conviction that it is the best method. The constitutions of most States provide that all properties shall be assessed for taxation, and that taxation shall be uniform. This provision precludes any method of taxation based upon output or profits, as well as a specific tax of any kind on mining property or products. In some of the States the constitution has been so framed or amended as to permit specific taxes, but the limitation on tax laws that they shall be otherwise uniform, is very general throughout the United States, and there is a strong sentiment in favour of an assessed value of all tangible property as the foundation of a uniform rate of general taxation. The advantages which, it is claimed, might result from the successful application of these principles to the taxation of all mineral deposits, call for rather extended examination.

It is usually provided that all property shall be assessed at its actual value. In practice, however, all property is almost universally valued at less than its actual worth. So long as a common measuring-stick is applied within the limits of a taxing jurisdiction, little harm results; but where municipalities with different standards of assessment are yoked together for taxation purposes, some method of equalization must be adopted in order that the burden which is common to all may be fairly distributed. Suitable machinery to attain this end is provided in most of the States by tax commissions or boards of equalization. The actual work of assessment is in the hands of local assessors, usually elected by the people of the community, and the natural tendency under such circumstances is towards a low level of valuation.

The Finlay Method of Valuation

The State of Michigan has applied engineering principles to the valuation of mines for taxation purposes. Local conditions had not a little to do with the departure. The extensive iron and copper mines lie in the northern peninsula, and are separated from the main body of the State by the waters of Lake Michigan. The lower peninsula is for the greater part a farming country. The northern peninsula has little farming value; its inhabitants are chiefly miners, or are dependent for their livelihood upon the mining industry. The people of the lower peninsula contended that the mines did not bear a fair share of the state taxation, while in the north the inhabitants resented what they considered an attempt to burden them with an unjust proportion of the amount. Agitation on the hustings and in the legislature was perennial. It chiefly centered about the question of the sufficiency of the value placed upon the iron and copper mines. At length, in 1911, the State Tax Commission employed Mr. J. R. Finlay, a well-known mining engineer, to value the mines. This, Mr. Finlay and his assistants proceeded to do, on the basis of five factors, (1) the tonnage of ore contained in the mine, (2) the life of the mine, determined by the average annual production, (3) the cost of operating the mine, (4) the annual receipts from ore, and (5) the rate of interest for ascertaining the present worth of deferred production.

The iron and copper mining companies had on hand in nearly all cases, diamond drilling records, results of geological investigations and similar data.

All such information was placed at Mr. Finlay's disposal. His method of valuation may be thus illustrated. Take any given mine; call it the Iron Hill. The bore holes put down by the company owning it had already disclosed approximately the extent of the ore body, its length, width, and depth. This information, with geological data as to the probable nature and extent of undisclosed ore, enabled an estimate to be made of the total tonnage in the mine. The average production of the last four or five years gave the rate at which the mine was being exhausted, and consequently the length of time it might be expected yet to operate. The receipts from the sales of ore for the same period gave the average value of the ore per ton. The expenses of operating the mine averaged for a like number of years, gave the cost per ton. Mr. Finlay's examination, let us assume, showed that the Iron Hill mine contained 10,000,000 tons of ore, that it was producing 500,000 tons annually, and hence would have a life of twenty years, that the average price received for ore was $3.50 per ton, and that the average cost of producing it was 3.00 per ton. It was evident, then, that for twenty years the Iron Hill mine would or could produce 500,000 tons of ore annually, at a profit of 50 cents per ton. The net income of the company would therefore be $250,000 per annum. Discounting at six per cent. an annuity of $250,000 per annum, payable for twenty years, Mr. Finlay arrived at the value of the mine, which in this case would be $2,867,475. The Iron Hill mine would therefore be entered upon the assessment roll for this amount, and the state, county and township tax levied upon it. The valuation for each succeeding year would, of course, be on a descending scale, ending in nothing for the year in which the mine should be worked out. Mr. Finlay's survey of the iron mines of the State gave them a valuation of $129,000,000; but the companies complained so loudly at this result that the Tax Commission reduced the assessment to about $85,000,000, increasing it the next year to $90,000,000. At this figure it has practically stood ever since that time, the amount of ore brought in sight each year equalling the amount extracted.

The application of the Finlay method to the copper mines produced an entirely different result. The valuation was about $69,000,000. This was far below the aggregate of the existing assessments, and also far below the aggregate value of the shares of the copper companies as shown by the market quotations. The companies asked for the maintenance of their assessments at the old valuations. To this request the Tax Commissioners also acceded, and the copper mines have remained at about their old figures.

Minnesota has adopted the general principles of the Finlay method of valuation for the great iron deposits of that State, and has adapted them to local conditions, but fixes the assessment at only 50 per cent. of their value, this being the legal standard of all mine assessments. An elaborate system of classification of productive mines and unproductive mines or prospects, with a varying standard for valuation in the several classes, has been worked out in the endeavour to arrive at equitable results.

The immense, homogeneous bodies of ore contained in the great iron and copper mines of these two States, presented the best possible conditions for the successful operation of the valuation system, which has been further favoured

by an unusually able and experienced body of officials charged with the administration of the law. There are features of this system in its attempt to place mines and mining lands on the same basis for assessment and taxation as other tangible property, that are attractive, especially in view of the practical difficulties that have been experienced in operating the net profits system with the nickel companies in Ontario. Its treatment of the owner of presumably valuable deposits who refuses or fails to develop or work them, is also inviting. The Commissioners, however, were not satisfied that even under its efficient operation in Minnesota and Michigan, it was as fair to the miners or as beneficial to the State as a good system of taxation on net profits would have been.

Effects of the ad Valorem System

Undoubtedly one effect in these States has been to retard development. The mining companies are naturally unwilling to explore their properties much in advance of their actual requirements, since to do so is simply to establish ore which at once becomes subject to taxation.

It has been urged that the ad valorem system is wholesome in its tendency to check the propensity of great corporations to acquire control of an unduly large share of ore reserves. Unworked tonnage in Ontario is now carried without expense, and it is contended that the unchecked acquisition of mining lands by a few powerful concerns might result in a monopoly with the power of controlling prices and preventing competition, and also in depriving the Province of the revenue it would receive if other companies were working the unused reserves at a profit.

Ample ore reserves, on the other hand, are necessary for operations on a large scale. No prudent company would enter on the heavy expenditure required for mining, smelting and treatment works unless possessed of sufficient ore to ensure a long life, and provide a reasonable return upon the capital invested. Strong, progressive companies able to keep abreast of modern developments in mining and metallurgy, assist the industry, and are desirable in the public interest. The danger of any mining industry passing into the hands of one or two companies by a monopoly of large ore reserves, to the public detriment, may be exaggerated. An attempt to acquire such a monopoly might at any moment be frustrated by the discovery of new ore bodies, such as are brought to light from time to time. In the last resort, such a situation should be amenable to legislative control; but there are natural limits beyond which ore reserves cannot, at any rate by purchase, be increased, since money invested against long-deferred operations accumulates heavy charges, and may even, if the period be sufficiently prolonged, result in a loss. As for the Provincial revenue, its claims are only postponed. When the reserves come into use, the Province will get its share.

It is not in the public interest that any industry should be harassed by unfair taxation. The chances of hardship and injury to the mining industry on taxation of profits alone, are remote. Such a result is possible, and even probable, under the best attempts to place a definite value on undisclosed deposits of ore.

The history of iron mining in Michigan proves the truth of the latter statement. Official statistics show that 13,151,612 (long) tons of ore were shipped from

the iron mines of that State in 1915. The receipts from sales of ore were $36,745,878.91, or $2.79402 per ton. Much of the ore is mined subject to payment of a royalty to the owner of the fee, that is, the former owner of the property who reserved a royalty on the ore. The average royalty, spread over the entire quantity of ore shipped in 1915, was $0.23136 per ton. Including the royalty, the average profit to the producers of ore was $0.52380 per ton. Out of this profit the royalty charge had to be met, and in addition, taxes averaging $0.13784 per ton. That is to say, the net profit remaining to the mining companies, after allowing for certain smaller items, was $0.14674 per ton, out of the gross profit of $0.52380. Thus, of the selling price, nearly one-half of what was left after deducting expenses of production, went to the owner of the fee, and the remainder was shared in nearly equal proportions by the producer and tax-collector. Before payment of the royalty, the taxes amounted to 26.31 per cent. of the profits; after payment of the royalty, to 47.13 per cent. When royalty, taxes, and minor charges were paid, only 28.01 per cent. of the original profit per ton was left for the miner.

In 1914 the case was even less satisfactory to the mining companies. They sustained an average loss of not less than $0.07712 per ton of ore after payment of royalty; yet the taxes collected from them amounted to $0.12009 per ton. The year 1914 cannot be considered a representative one, because of the disturbance in the iron ore trade caused by the outbreak of the European war; yet in an ordinary season the rate of taxation on the iron mines of Michigan, is not less than 15 per cent. of their gross earnings. For the period 1911-1915 it was considerably more. On 54,830,513 tons of ore shipped the gross profit per ton was $0.54468, out of which the taxes averaged $0.13646 per ton per annum, or almost exactly 25 per cent. The Commissioners would not like to see so heavy a burden laid on the mining industry of Ontario.

Cases of hardship have arisen, in which ore has been developed on ordinary farms under options that have not been taken up, or where unprofitable mining leases have been forfeited. The owner of the land is at the mercy of the assessor, with unsalable ore on his hands liable to taxation, possibly beyond his means. In such a predicament the farmer stands a good chance of losing his land.

Difficulties of Appraisal

The intrinsic physical difficulties in the way of obtaining an exact valuation of mineral deposits, militate against the adoption of this method, except as a last resort. The valuation of a mine requires experience and trained judgment of a kind and in a degree far beyond that which can be expected of a township official, who moreover, is likely to be beset by local influences and swayed by local affiliations. A farm lies open to view; a building site bears ascertainable relations to other sites of known value; the trees in a forest may be counted, or their number and worth closely estimated: but none of these tests is available for the valuation of a mine. Where bodies of mineral are large, regular in outline and uniform in quality, such as a coal mine or even a great lens of iron ore, a complete and necessarily expensive set of borings or excavations may supply fair data for estimating the contents, and so supply one essential factor for the valuation of a mine.

It is conceivable that the immense masses of pyrrhotite mixed with chalcopyrite, which compose the nickel-copper mines of Ontario, might be measured by means of diamond drill borings, and their contents estimated and valued on the basis of the records obtained. It may be pointed out, however, that the nickel companies themselves have occasionally been at sea as to the extent of their ore reserves. The Canadian Copper Company, for instance, had made extensive preparations for transferring its operations from the Creighton mine to the lower grade Frood, when further drilling at the Creighton proved unexpected reserves of ore, and changed the whole complexion of the company's prospects. The Murray mine was prospected and partially developed without disclosing the large ore body that has recently been proven, and drilling by the Mond company has shown the Levack deposit to be much more extensive than was originally supposed. In fact, the necessary data for an exact valuation of the nickel-copper mines of the Province do not as yet exist.

Even in the capable hands which administer the ad valorem system in its highest development, it has been found necessary to commit a wide discretion of adjustment to the officials. A factor for that purpose has in practice been added to the Finlay factors of valuation. On examination this appeared to be quite as influential as any other of the elements employed to fix the taxable value, and to be in effect nothing else than an estimate of the probable profits, which after all is the best guide to the true value of a mine.

Taxation of Profits

From what has been said it is evident that the ad valorem system ultimately rests on net profits. Unless a profit can be obtained by working a mineral deposit, it has no value; and the sum a working mine or any other property is worth depends upon the profit which it is producing, and will continue to produce. Where the object in view is revenue, the more logical way is to tax the profits as they are realized. Since these cannot be accurately predicted, they cannot be accurately capitalized. Should they prove smaller than was expected, the tax is less, and no injustice has been done; should they prove greater, the tax is correspondingly increased. The net profit system automatically adjusts itself to the conditions from year to year during the lifetime of a mine, and takes account of all changes in expenses and returns.

The Commissioners have found a decided preference, both in the United States and in Canada, for the net profit tax, and are of the opinion that a system of mining taxation whereby a fair and reasonable rate is levied upon the net annual profits of producing mines, is better suited to the conditions in Ontario than any other known method, is just and equitable to all parties concerned, and in the best interests of the Province. It appeals to the sense of fairness, and is allied in principle with the income tax, which is being widely adopted both in Europe and America. In taxation of income, and in succession and death duties, a fair progressive increase in the rate is a normal feature.

A change to any other system would meet with opposition from the mine-owners of Ontario. When the Dominion government was considering the war tax at the last session of Parliament, it was urged on behalf of the mine-owners

of this Province that the basis of the Ontario law should be adopted, in so far as mining companies were concerned. This special impost the mining industry of Canada is bearing, in common with all other industries, for the purposes of the war.

Operating the Ontario Act

In arriving at the net profits, the Mining Tax Act requires that from the gross receipts derived from the year's output, or if the ore is not sold but is treated by or for the owners at the mine or elsewhere, then from the actual market value of the output at the pit's mouth, there shall be deducted all operating expenses. These include freight, working charges, salaries and wages, the cost of power, light, food or provisions (when furnished), explosives, fuel and other necessary supplies, protection, insurance, depreciation of buildings and machinery (not exceeding 10 per cent. per annum), and cost of new work, either at the mine itself or on other mining properties held by the same owner. No other allowance is made for the cost of plant, machinery, equipment or buildings, for capital invested, interest or dividends, nor for exhaustion of the mine. Where there is no means of ascertaining the market value of the mineral output, or where there is no established market price, the value is to be appraised by the Mine Assessor.

The rate of depreciation allowed for mining plant and equipment, viz., 10 per cent., is probably too low. Mine buildings and plant cease to have value when the mine is exhausted. Machinery is subject to wear and tear, and as in all other industries, quickly becomes obsolete, so rapid is the march of improvement, especially in metallurgical methods. The depreciation rate might well be increased to 15 per cent. at least.

The suggestion has been made that instead of considering each year's transactions as a separate unit, expenses and receipts alike should be averaged over a period of years, say three or five. One effect of this would be that where unusual expenditures have been incurred, the excess would be spread over the period, and not concentrated upon a single year. Conversely, if the returns exceed normal, the surplus would be conserved to meet a possible deficiency in the future. In either case, the tendency would be towards an equalization of taxation from year to year, to the benefit of municipal financing.

Any advantage which would spring from the adoption of this suggestion would be to the municipality, and not to the Province. This would not be good ground for rejecting it; but there are other reasons for doing so. In rich and short-lived mines the advance to prosperity is rapid, and the decline equally so. The time when a tax can best be borne is when the mine is flourishing. But when the end is in sight, and profits dwindle, the ability to pay is reduced, possibly gone entirely. The adoption of a five or even a three-year average would undoubtedly tend to shift the high point of taxation to a later period in the mine's history, and might entail a burden on the closing years which it could not bear. There is, besides, the decided practical advantage of the present system in definitely closing the account at the end of every year, and so excluding the possibility of reviving old claims or past controversies.

The present Act exempts from taxation the first $10,000 of net profits. This feature serves a useful purpose in encouraging the development of properties where the prospects are uncertain. It is in the nature of a premium to the small owner who develops his own mine; in such cases a full year's work might often result in less than $10,000 profit, and it is in the public interest to encourage the working of small mines by individuals or groups of individuals.

The exemption of mine buildings and equipment is just, when coupled with a profit tax, for when a mine is worked out, buildings lose their value, and machinery must be scrapped. They are therefore entitled to be regarded as an integral part of the mine.

The operation of the Act with respect to the gold and silver mines presents few difficulties. Gold is invariably extracted from the ore at the place of production, and this is now largely the case in Ontario with silver as well. Only about 16 per cent. of the silver mined in Ontario is now contained in exported ore, the remainder being either recovered in works situated at the mines themselves or in refineries elsewhere in the Province. The cost of extracting the gold and silver is easily ascertained. The Mine Assessor has simply to deduct from the value of the metals recovered the cost of treatment, freight and other expenses allowed by the Act, or the actual charge for milling and refining, if done by a custom works, and to collect three per cent. on the difference, which represents the net profits.

The Commissioners would observe that the scarcity and increased cost of labour, and the rise in the price of supplies during the last two or three years which is still in progress, have borne more heavily upon gold mining than upon any other branch of the industry. The value of gold expressed in dollars and cents is absolutely fixed, and a general rise in prices consequently depresses its purchasing power. All other metals, on the other hand, have gone up in price, some of them, such as copper and silver, very largely. There is no reason to think that these conditions, as affecting gold, will be other than temporary. In Australia, where excess profits taxation has been found necessary for war purposes, as in most British communities, the gold mining industry has been exempted from this increase.

Taxation of Nickel Companies

The case of the nickel companies is more complicated. When the ore is not sold, the Act requires the tax to be collected on its value at the pit's mouth, less the specified deductions. "If there is no means of ascertaining the market value, or if there is no established price or value," the value of the ore at the pit's mouth must be appraised by the Mine Assessor. Practically the whole of the nickel ore is raised by the two great operating companies themselves, and they are not at all dependent upon other nickel miners for any part of their supply. There is no open market, and no market price or value anywhere in America for nickel ore, such as, for instance, there is for iron ore at Lake Erie ports. The price paid for the small quantity of ore bought at Sudbury can hardly be said to establish a "market price or value." There is an entire absence of competition. If neither of the operating companies will buy the ore, it cannot be sold.

Neither is there any real purchase and sale of the matte produced by the Sudbury furnaces. The company in Ontario simply ships the matte to the same or an affiliated company in Wales or New Jersey at an arbitrary or bookkeeping price. The price is not material, since there is no real change in the ownership. In the case of the Canadian Copper Company under a long-standing agreement with the International Nickel Company and its predecessor, the Orford Copper Company, it is 10 cents a pound for the nickel contents of the matte and 7 cents for the copper.

The Mine Assessor was therefore confronted with the difficult problem of ascertaining the true value of the nickel ores of Sudbury at the pit's mouth. The method he adopted is shown by his memorandum, printed in the Appendix. Shortly, it was as follows:—

The nickel industry was regarded as comprising three stages, (1) mining, which implies possession of the ore; (2) roasting, smelting and converting, and (3) refining and selling. While the ore is the primary source of all the profits, it would not be reasonable to demand that the subsequent operations should be carried on without profit, or that the whole of the gain should be credited to the ore. If the ore were smelted or refined by an independent company, these processes would be entitled to their fair share of the increased value, and they should not be treated differently merely because they were performed by the company which owns the ore. The Mining Tax Act, moreover, expressly bases the taxation on the value of the ore at the pit's mouth, and consequently excludes all the values added by subsequent treatment. The question was further complicated by the fact that after the production of the matte, the labour and capital employed in the subsequent processes of refining are employed without the Province, beyond the direct reach of its taxing power. In distributing the profits fairly over the above three stages of development, the elements of difficulty and skill were clearly entitled to consideration. Neither the mining nor the smelting of the nickel ore differs materially from standard practice, say in the production of copper. Nor does either operation call for an unusual degree of skill. The Mine Assessor regarded the refining of nickel as a matter of greater difficulty, and demanding a higher degree of metallurgical ability. The companies contended strongly that the refining and marketing combined were entitled to a larger share of the total profit than either the mining or smelting. The Mine Assessor finally decided that out of 100 parts of profit, the second stage of smelting and converting should be credited with 20 parts, and concluded that a fair division of profit would allot 40 per cent. to mining and possession of the ore, 20 per cent. to smelting and converting, and 40 per cent. to refining and sale. The profits of the International Nickel Company for the three fiscal years ending 31st March, 1915, averaged about $5,000,000 per annum; 40 per cent. of these profits allotted to the ore at the pit's mouth would be $2,000,000, which at three per cent. would yield a tax of $60,000. Practically the whole of the expenditure required in the neighbourhood of the mines for roads, water supplies, schools, hospital accommodation, and for other public needs, was made by the company. It was considered just to credit the company with the one-third share which would have gone to the municipality had one been organized, as it might easily have been. This left the net amount to go to the Province at $40,000.

The company objected to adjustment upon this basis, to which they consented only after prolonged discussion. It is only fair to state that all indications pointed at that time to a decrease rather than an increase in the company's gross returns and profits, since at that time they expected shortly to begin the treatment of much lower grade ore. The taxes payable from 1912 to 1915 inclusive have been paid accordingly.

The outbreak of the great European war, which at first staggered the nickel and other mining industries of Ontario, speedily led to an unprecedented demand for nickel and copper, and to the operation of the mines and works of the International Nickel Company at their maximum capacity. Prices for nickel and copper both rose, especially for the latter, which, about the end of 1916, went to 35 cents a pound. The increase in production and price naturally increased the company's profits. For the year ending 31st March, 1916, these, according to the company's own showing, were $11,748,278.53. Quite evidently $60,000 no longer represented a fair amount of taxation, and a revision of the arrangement is clearly in order.

A similar method applied to the lower grade ores and smaller operations of the Mond Nickel Company under similar circumstances fixed the taxes payable to the Province at $4,000, also after making allowance for this company's quasi-municipal expenditures. The Mond company was at the time engaged in making large and costly changes, including the opening up of new sources of ore supply. In the course of these operations they had expended unusually large sums for development, with the result that the deductions allowed by the Act had on their contention left nothing in the way of taxable profits.

The lands, buildings, mineral, plant and concentrators of both companies in Ontario were under the general law exempt from assessment and taxation.

The existing method of ascertaining the value of nickel-copper ore at the pit's mouth when there is no open market or other available means of ascertaining its market value, is not satisfactory. The onus should not be upon the officials of the Province, but upon the company. Provision should be made to meet such conditions, or any case where the costs of all stages of treatment cannot be clearly ascertained, by directing the Mine Assessor to fix the profits to be taxed at an amount based upon the price or value of the refined products, less the present statutory deductions, and such further deductions for the actual costs of treatment as the owner shall establish to the Mine Assessor's satisfaction. The opinion of the Mine Assessor to be final, subject, as at present, to appeal to the Mining Commissioner or the Ontario Railway and Municipal Board.

The present system of taxation has been in force for ten years. At the time of its adoption the two operating nickel companies were not in so prosperous a condition as they are to-day. It was only in 1910 that the International Nickel Company, organized in 1902, paid its first dividend on the common stock. Moreover, other processes for the refining of nickel-copper ores, such as those of Sudbury, are now available. The Hybinette process introduced into Norway eight or nine years ago has been perfected, and is now to be employed at Sudbury. In view of the changed conditions both as to the prosperity of the companies and the growth

of knowledge as to refining methods, in addition to requirements for increased revenue, it would appear that the methods adopted by the Mine Assessor, while applicable at the time, should now be modified. In view of this, the Commission recommend the methods of taxing the nickel-copper companies described in the preceding paragraph.

The Interest of the Municipalities

An important provision of the Tax Act entitles the municipality in which a mine is situated to one-third the tax; an exception is made of Cobalt, where the share is one-half. By exempting mineral deposits and mining buildings from municipal taxation, the Legislature withdrew from local bodies the power of levying upon them for public needs, and substituted a specific proportion of the mining tax on income. There can be no doubt that the communities which spring up so rapidly when a rich mining district is opened up, have many troubles in the financing of their public needs. They find it difficult to sell their debentures, owing to the scepticism with which investors usually regard the future of a mining camp, and it is impossible to raise out of current taxation sufficient money to instal water and sewerage systems, put down pavements, build schools, and generally provide the improvements required.

How largely the receipts from mining taxation bulk in the finances of the town and township municipalities which include in their limits operating and profitable mines may be seen from the following figures:—

Period	Municipality	Total Taxation	Income Tax from Mines	Proportion of Mining to Total Taxation
		$	$	Per Cent.
1907–1916.......	Town of Cobalt..............	782,576	384,851	49.1
1907–1916.......	Township of Coleman	528,057	405,709	76.8
1912–1916.......	Town of Timmins............	112,915	50,477	44.7

The item of receipts from mining companies, owing to its unusual nature, has given municipal clerks and treasurers a certain amount of trouble. The law assumes that the same rate as is levied on other kinds of property will be levied on a mining company's income, but fixes the maximum amount that may be collected at one-third of the total tax under the Act. In practice the municipality always collects the maximum amount. In some cases the company's income is assessed at the sum, whatever that may be, which at the tax rate will yield one-third of the total tax under the Tax Act as ascertained from the Mine Assessor, and in other cases the tax is simply entered in the treasurer's accounts as receipts, without reference to any assessment whatever. It might be advisable to prescribe some uniform method to be adopted by the municipalities in dealing with this matter.

The township of Coleman and the town of Cobalt have had longer experience of the existing law than any other of the northern municipalities. The former has been able to construct a first-class system of automobile roads, of the greatest value to the mining community. One witness noted that the mining tax also

more than paid for erecting and maintaining the schools of the township. Cobalt has installed water and sewerage systems, paved her streets, built a commodious town hall, and made other improvements. The town of Timmins and township of Tisdale are both in the early stages of development, and the path of the municipal financiers is not an easy one, as a reference to the testimony printed in the Appendix will show. The mining companies do not object to a share of the Provincial tax going to local requirements, since they benefit largely by the improvements upon which the money is expended.

The Commissioners believe that so long as the taxing disability of municipalities remains as regards mines, it is essential to continue to them a share of the mining taxes. The municipalities could not get along without it; indeed, their representatives urged that the proportion should be increased, or even that the entire revenue collected from companies within their bounds, should for a term of years be handed over for expenditure on local requirements.

The proportion adopted at the beginning was one-third, the larger percentage allowed to Cobalt being probably due to the difficulties created by the rocky and uneven site selected for the town. The Commissioners are of opinion that the municipalities should receive the normal proportion of the tax on mining companies, namely, one-third, so long as it remains at three per cent.; and that should the rate be increased, the position of the municipalities should remain unaffected. Thus on a rate of three per cent. they now receive one per cent.; on a four per cent. or five per cent. rate, they would continue to receive one per cent. In this way, while the proportion they would receive of the increased tax would be lessened, their annual receipts, presuming the taxes under the Act to remain at the same amount, would remain the same as now. It might be wise to place a maximum limit on the tax payable by any company to a municipality in any one year, of say $35,000 or $40,000, which exceeds the largest sum hitherto so paid.

When a mine or mines and smelter, or other plant for the treatment of ores, belonging to any one company, are not situated in the same township or municipality, provision might be made for the division of the income from the tax between two or more municipalities or townships. This provision should apply only to plants that are situated say within fifty miles of the mine or mines, so as to confine the benefits from the tax to the district in which the ore is mined.

Moreover, provision might be made for an equitable division of the municipal share of the tax in the case of a municipality which from its proximity to the mines or plant of a mining company is put to additional expense, although none of the works or property of the company is within its limits. A large number of employees, for instance, might make their homes in such a municipality with resulting expenditures for providing additional streets, water, fire protection and other municipal requirements. The Mining Commissioner might be empowered to distribute the municipal tax in such proportions as seems to him proper.

What the Profit Tax Has Yielded

The sums paid by the several branches of the mining industry directly into the Provincial treasury by way of profit taxes, from the time the Mining Tax Act took effect in 1907 down to the end of the last fiscal year, 31st October, 1916, were as follows:—

Silver mines	$927,570 60
Gold mines	142,239 77
Nickel-copper mines	264,033 53
Miscellaneous mines	1,899 72
Total	$1,335,743 62

This sum, however, is only part of the whole amount paid by the mining companies. (1) The municipalities in which the mines are situated received their due share of taxation under the Tax Act. (2) Large sums were expended by mining companies for what were virtually municipal purposes, such as roads, etc., where municipal organization did not exist, part of which, not exceeding one-third of the total tax accrual, was allowed as deductions. (3) At Cobalt, the Timiskaming and Northern Ontario Railway Commission had been invested with the mining rights of part of the town site, and these were leased to mining companies in consideration of substantial royalties. The T. and N. O. railway being a government line, the revenues under these leases, though paid to the Railway Commission, were to all intents and purposes government receipts. (4) There were certain silver mines, notably the O'Brien and Hudson Bay, which under special agreements paid direct to the government a royalty much in excess of the 3 per cent. tax. (5) Finally, several mines, under the terms of purchase from the Crown, paid a royalty of 10 per cent. on the value of the ore produced. The principal mine in this class was the Crown Reserve. All the Cobalt silver companies, whether holding directly from the Crown, or from the T. and N. O. Commission, paid municipal taxes. By virtue of section 23 of the Mining Tax Act, companies paying a higher rate under special agreement were exempt from the 3 per cent. tax.

The total payments by the mining companies to the Province and the municipalities to 31st October, 1916, may be summed up as below. It should be explained that the figures do not include certain small items of taxation paid by the mining companies other than on income, and that the allowances for quasi-municipal expenditure, in the absence of municipal organization, were in the Sudbury district only.

To the Province:—		
Proportion of tax on profits under Mining Tax Act		$1,335,743 62
Royalties under special agreements		1,903,993 96
Paid T. and N. O. Ry. Commission for mining rights and royalties		894,103 47
Total to Province		$4,133,841 05
To Municipalities:—		
Proportion profit tax under Tax Act	766,263 66	
Taxes paid by companies holding from T. and N. O. Commission	95,019 86	
		861,283 52
		$4,995,124 57
Allowed in lieu of municipal taxation		80,000 00
Total		$5,075,124 57

Additional receipts from the Cobalt area included the sum of $1,085,000 received from the sale of Cobalt lake, and an aggregate of about $700,000 for the Crown Reserve claim and part of the Gillies limits. These sums, however, were purchase moneys, and cannot be considered in the light of taxation.

Dividends Paid by Mining Companies

The chief metals of production in Ontario are gold, silver, nickel and copper. That the companies engaged in these branches of mining have prospered during the last decade is amply proven by the following figures showing the dividends paid by them from 1906 to 1916 inclusive. Silver mining companies began paying dividends in 1906, gold mining companies in 1913. The dividends given for the nickel-copper companies cover the period from 1910 to 1916 inclusive; previously, the returns were on a much smaller scale.

Silver mines	$65,181,743 00
Gold mines	9,786,625 00
Nickel-copper mines	36,508,153 00
Total	$111,476,521 00

The figures for the silver mines might have been increased by adding several million dollars paid in profits to private owners. Most of the silver and gold companies have their head offices in Ontario, and all of the gold, and about 85 per cent. of the silver is recovered here. The nickel-copper companies have their head offices outside of the Province, and, as is known, smelt to an 80 per cent. matte, which is exported for final treatment by one company to the United States, and by the other, to Wales.

It is matter for congratulation that profits can be made from working mines in Ontario which permit of the payment of dividends on such a scale. The figures quoted are irrefutable evidence, if any is now needed, of the mineral richness of this Province.

On the other hand, mining is a business by itself. It takes large risks, and demands large returns. A yield on capital quite satisfactory in an ordinary trading or manufacturing business, is much below the standard applicable to mining. Many mines, especially of the precious metals, are short-lived. For instance, the silver deposits at Cobalt were discovered in 1903, yet several of the richest deposits have to all appearances been worked out, or nearly so, and the production of the camp as a whole has for several years been declining. While a mine lives, it must return all the capital expended in purchase, development and equipment, otherwise a loss is sustained. In addition, it should make a return sufficiently attractive to compensate the owners for risking their money and induce them to continue in the business. A workable mining proposition should yield annually during its lifetime over and above the net profit tax, a reasonable dividend (say 15 or 20 per cent.) on the capital expended in purchase, development and equipment, together with a further sum which at a fair rate of interest (say 5 or 6 per cent.) will replace the capital so expended. The practice in Ontario has been to return surplus funds to shareholders in dividends, rather than formally to amortize capital, but the principle remains the same. Many of the Cobalt silver mines have repaid in dividends their entire share capital, to say nothing of the actual capital outlay, some of them several times over. Yet it is often forgotten that real profits to the shareholders can only begin after proper provision has been made for replacement of capital. Hence it is that shares of successful mining companies frequently sell above their intrinsic value, purchasers having regard solely to the high rate of

dividend, and overlooking the fact that the returns are only in part profit, the remainder being capital.

The Rate of Taxation

The present rate of profit tax, 3 per cent., has lasted for ten years. As regards a rate for the future, much will depend upon the requirements of the Province. It may be expected that these will not be less in the future than in the past; on the contrary, they are likely to be greater. The tendency towards increased public expenditure has of late years been very noticeable. It is felt in the United States, in Great Britain, on the continent of Europe, in fact, everywhere. Better education, better roads, sanitation, water, light, telephone communications, postal facilities, etc., are being constantly demanded. The growing humanitarianism of the age calls for better care of the feeble and defective, and for more enlightened methods of dealing with the criminal. The progressive programme of hydro-electric development, good roads and the opening up of Northern Ontario, will entail large expenditures, and probably require the provision of new sources of revenue, or the enlargement of old ones. The care of wounded and invalided soldiers, the readjustment of economic conditions on the return of peace, and other measures which will probably then be necessary, will also call for the opening of the public purse, probably to a generous extent. It is the part of wisdom to prepare for such a state of affairs.

If in view of the increased revenue which will be required, it should be necessary to call upon the mining industry for a larger contribution, the Commissioners are of opinion that the rate on the net profits should not exceed five per cent.

Special War Taxation

A war tax of 25 per cent. on the profits of industrial companies in excess of seven per cent. was imposed by the Parliament of Canada under the Business Profits War Tax Act, 1916. The tax is retroactive, and is to be levied for three years upon the profits in any fiscal year or accounting period, after 31st December, 1914. In the case of mining companies, the Act provides that in determining the profits, allowance should be made for exhaustion of the mine, but how this allowance is to be fixed or ascertained the Act does not say. The first instalment of taxes became due on 1st November, 1916. It is not possible, as yet, accurately to gauge the measure of taxation which this Act will place on the mining industry of Ontario, but figures confidentially supplied the Commissioners show that while it lasts it will probably be at least equal to that now levied by the Province. As will be observed, the tax is upon the profits, and thus conforms in principle with the Mining Tax Act of Ontario.

The taxation of British companies for war purposes is still heavier. All are required to pay 50 per cent. of profits realized in excess of their pre-war average, and in the case of "controlled" companies, engaged in the production of war material, the government now takes in taxes the entire excess.

It is obvious that a company of British origin, employing British capital in Canada, with head office, say, in London, subjected to a war tax of such dimensions, ought not to be asked to pay as well the Canadian tax levied for the same purpose.

The Canadian Act accordingly provides that any war tax paid in Great Britain, or any of the allied countries in respect of any business liable to such taxation in Canada, shall be deducted from the amount of the tax that would be otherwise payable. A like provision in the British Act permits the deduction of any tax paid on excess profits or similar duty imposed outside the United Kingdom. A foreign or colonial tax, for example the Profits Tax imposed in the Transvaal, is allowed as a deduction.

These special measures of taxation owe their origin to the fact that in many lines of production profits were materially increased by reason of the war, and to the feeling that such unusual gains could legitimately be called upon for a corresponding contribution towards war expenses. It is evident, however, that when the war is over, and trade resumes its wonted channels, these unusual gains will disappear, and with them the taxes which they bear. For this reason, the Commissioners do not make any suggestion as regards the weight that should be given to these conditions in amending the Mining Tax Act, except to say that in their opinion, the minimum degree of consideration should include all such war levies in the deductions authorized from gross receipts for the purpose of ascertaining net profits.

Reference should be made to the memoranda respecting Mine Taxation handed in by Mr. P. A. Robbins, General Manager of the Hollinger Consolidated Gold Mines, Limited, and Mr. C. V. Corless, Manager of the Mond Nickel Company, also to the evidence given on the subject by these and others connected with the mining industry. They are printed in the Appendix in the section devoted to Taxation of Mines. It is not deemed necessary to deal with their representations here, but the Commissioners are indebted to these gentlemen and their companies for the ability and care exhibited in preparing the most useful information which these memoranda contain.

CHAPTER XIV

Bibliography of Nickel

[NOTE.—The references mentioned in the bibliography of papers and reports relating to the geology and mineral resources of New Caledonia, printed as appendix to F. D. Power's paper on the "Mineral Resources of New Caledonia" in the Transactions of the Inst. Min. and Metallurgy, 1899-1900, vol. VIII, pp. 464-469, are not included in the present bibliography; these two bibliographies, therefore, supplementing one another in this respect. This bibliography deals exclusively with the manufacture of nickel, and geology and development of nickel ore deposits, and, consequently, it does not pretend to cover properties of nickel (physical, mechanical, and chemical), ferro-nickel, nickel alloys and applications of nickel in the mechanical and chemical trades.

Some of the more important papers on the geology of the Sudbury ore bodies are marked with a single asterisk, thus *; on the treatment and general metallurgy of nickel ores, with a double asterisk, thus **.]

1803—Richter, J. B.
A new, perfect metal present in entirely purified nickel (Niccolanum).
Crele, Chem. Annalen, 1803, vol. II, pp. 383, 384.
Annales de Chimie, 1805, vol. 54, pp. 302-311.
Gilbert, Annal., 1805, vol. XIX, pp. 377-382.
Journ. de Phys., 1805, vol. 61, pp. 149, 150.
Nicholson, Jour., 1803, vol. XII, pp. 261-265.

1804—Richter, J. B.
On the best hitherto known methods of purifying cobalt and nickel from bismuth, arsenic, iron and copper, which in general accompany these metals, but particularly on the best methods of separating cobalt from nickel, or nickel from cobalt, in the large way.
(Transl. from Neues Allgem. Jour. der Chemie.)
Tilloch, Phil. Mag., 1804, vol. XIX, pp. 51-54.
Annales de Chimie, 1805, vol. 53, pp. 107-114.

Thénard.
Memoir on nickel.
Annales de Chimie (30 Floréal, an XII), 1804, vol. 50, pp. 117-133.
Tilloch, Phil. Mag., 1805, vol. XX, pp. 63-70.

1805—Bücholz, C. F.
Investigation into the different processes of obtaining the separation of nickel from cobalt.
Annales de Chimie et de Physique, 1805, vol. 55 (I), pp. 137-151.
Nicholson, Jour. Natur. Philosophy, Chemistry and the Arts, 1806, vol. XIII, pp. 261-267.
Tilloch, Phil. Mag., 1805, vol. XXIII, pp. 193-199.

1805—Richter, J. B.
On pure nickel.
(Transl.) Annales de Chimie, 1805, vol. 53, pp. 164-183.
Nicholson, Jour. Natur. Philosophy, Chemistry and the Arts, 1805, vol. XII, pp. 75-80.
Tilloch, Phil. Mag., 1805, vol. XXXIII, pp. 137-142.

1819—Berthier, P.
Analysis of arsenical nickel, and the arseniate of nickel of Allemont (Isère department).
Annales des Mines, 1819, vol. IV, pp. 467-482.
Annales de Chimie, 1820, vol. XIV, pp. 52-62.
Tilloch, Phil. Mag., 1820, vol. 56, pp. 295-299.

1824—Berthier, P.
On the composition of nickel oxide.
Annales Chim. Phys., 1824, vol. 25 (2nd series), pp. 94-98.
Karsten's Archiv f. Bergbau, 1826, vol. XI, pp. 401-406.
Schweigger's Jour. f. Chemie u. Physik, 1824, vol. 42, pp. 89-94.

1826—Erdmann, O. L.
On the large-scale production of nickel, with a few observations on white "tombac." (Weisskupfer).
Schweigger's Jour. f. Chemie u. Physik, 1826, vol. 48, pp. 129-152. (— Jahrbuch, vol. XVIII.)

1831—Liebig and Wohler.
Reduction of nickel oxide by carbon monoxide.
Poggendorff's Annalen d. Chemie u. Physik, 1831, vol. XXIX, pp. 584-586.
Jour. prakt. Chemie, 1831, vol. XI, pp. 397, 398.

1836—Berthier.
Action of lead on the arsenic-sulphur compounds of iron, cobalt, nickel and copper.
Annales de Chimie et de Physique, 1836, June, vol. 62, pp. 113-134.
J. prakt. Chemie, 1837, vol. X, pp. 13-28.

1837—Winkelblech, G. C.
On the combustion of some metals by sulphur. Behavior of nickel with regard to sulphur.
Liebig's Annalen d. Chemie u. Pharmazie, 1837, vol. XXI, pp. 36-38.
J. prakt. Chemie, 1837, vol. X, pp. 239, 240.

1849—Murray, Alexander.
The Wallace mine; and rocks on Spanish river, Ontario.
Canada Geol. Sur., 1848, 1849, pp. 40-45.

1851—Bredberg, B. G.
Report on the experiments carried out from 1849-1851 at the nickel smeltery Klefva (Sweden) for working the nickel-containing pyrrhotites occurring there into metallic nickel.
Erdmann's Jour. prakt. Chemie, 1851, vol. 53, pp. 242-248; vol. 54, pp. 79-83.

1851—Bredberg, B. G.
Nickel-tillverkning.
Stockholm, ofversigt of Kongl. Vetenskaps Academiens Forhandlingar, 1851, vol. VIII, pp. 169-174.

Gmelin, Leopold.
Handbook of chemistry. (Translated by H. Watts.)
1851, London, Printed for the Cavendish Society, vol. V, pp. 354-361.
Chapter on nickel.

Vivian, H.
Method of separating nickel and cobalt from copper ores in the process of smelting.
British Patent Spec. No. 13800, Nov. 4, 1851.
"The separation of nickel and cobalt, or either of them, in the form of 'arsenides from ores, slags, regulus, and other combinations or alloys of copper . . . by means of the affinity of nickel and cobalt for arsenic and of copper for sulphur.'"

1855—Ebermayer, E.
On the production of nickel at the Aurora smeltery.
Inaugural thesis, Goettingen, 1855.
Abst., Wagner's Jahresbericht, 1855, vol. I, pp. 21, 22.

Kerl,
Handbuch der metallurgischen Hüttenkunde.
1855, vol. III, section 1, p. 366 et seq.; and section 2, p. 391 et seq.
(Production of pure nickel by the de Ruolz and de Fontenay method.)

Patera, A.
On the separation of arsenic from metals in large-scale operations.
Oesterr. Zeit. Berg- und Hüttenwesen, 1855, vol. III, No. 22.
Dingler's Polytechn. Jour., 1855, vol. 136, p. 395.

Patera, A.
An advantageous method, adapted to large-scale operations, for the extraction of valuable metals from the Joachimsthal ores.
Jour. prakt. Chemie, 1855, vol. 67, p. 14 et seq.
Oesterr. Zeits. Berg- und Hüttenwesen, 1855, vol. 3, p. 377, 388.
Annales des Mines, 1855, vol. VIII (5th series), pp. 68-78.
Wagner's Jahresbericht, 1855, vol. I, pp. 20, 21.

1856—Deville, Henri Sainte- Claire.
Memoir on the production of extremely high temperatures.
(Fusion of nickel.)
Annales d. Chimie et de physique, 1856, vol. 46 (3rd series), pp. 201, 202.

Hauer, K. R., von.
On Patera's application of certain analytical methods to the substitution of metallurgical processes.
(Separation of nickel and cobalt from arsenic; separation of cobalt from nickel; precipitation of nickel; reduction of nickel oxide.)
Jour. prakt. Chemie, 1856, vol. 67, pp. 14-24.

Murray, Alexander.
Discovery of what in later years became known as Creighton mine, Ontario.
Canada, Geol. Survey, 1853-1856, pp. 168, 169, 176-181.

1857—Deville, H. Saint-Claire.
Some general methods for the preparation of elements (Ni).
Comptes-Rendus de l'Académie des Sciences, 1857, vol. 44, pp. 673-677.
J. prakt. Chemie, 1857, vol. 71, pp. 289-293.

1858—Cloez, S.
New methods for the treatment of speiss and "kupfernickel" (nickel arsenide).
Comptes-Rendus de l'Académie des Sciences, 1858, vol. 46, pp. 41-43.
Wagner's Jahresber., 1858, vol. IV, pp. 53-55.
Dingler's Polytechn. Jour., 1858, vol. 148, p. 206.

Stapff, F. M.
Concentration of nickel matte in Sweden.
Berg- und Hüttenmänn. Ztg., 1858, vol. XVII, pp. 353 and 371.

Stapff.
Production of nickel from sulphide nickel ores.
Berg- und Hüttenmänn, Ztg., 1858, vol. XVII, p. 377 et seq., p. 398 et seq.
Abst., Wagner's Jahresbericht, 1858, vol. IV, p. 52.

1859—Heusler, Fr.
The production of nickel and copper from nickel-bearing copper pyrites, as practised at the Isabellen smeltery, Dillenburg (Nassau).
Mitt. f. d. Gewerbeverein des Herzogtums Nassau, 1859, No. 14 and 15.
Abst. Wagner's Jahresbericht über die Fortschritte und Leistungen des chem. Technol., 1860, vol. VI, pp. 139-149.
Dingler's Polytechn. Jour., 1860, vol. 155, pp. 362-372.

1860—Casselmann, W.
On the composition of the nickel ores occurring near Dillenburg.
Liebig's Annalen d. Chemie u. Pharmacie, 1860, vol. 115, pp. 338-345.

1861—Hampe, W.
Analysis of a refined nickel speiss from the Oker plant.
Berg- und Hüttenmänn. Ztg., 1861, vol. 20, p. 349.

Percy, J.
Metallurgy: The art of extracting metals from their ores and adapting them to various purposes of manufacture.
1861, London, John Murray: Fuel, fire-clays, copper, zinc, etc.
pp. 375-378: The elimination of nickel and cobalt from copper.

1862—Becquerel, E. et Ch.
Electro-chemical reduction of cobalt, nickel, gold, silver and platinum.
Comptes-Rendus de l'Académie des Sciences, 1862, vol. 55, pp. 18-20.
Bull. Soc. d'Encouragement à l'Industrie Nationale, 1862, vol. IX, pp. 505-507. 2nd Series.
Wagner's Jahresber., 1862, vol. VIII, pp. 144, 145.

Ruolz.
Purification of commercial nickel.
Production of pure nickel from cobalt speiss.
Repertory of Patent Inventions, 1862, June, p. 460.
Mining Jour., 1862, No. 1385.
Dingler's Polytechn. Jour., 1862, vol. 165, pp. 131, 132.

1863—Odernheimer, F.
Mining and metallurgy in the duchy of Nassau.
(Das Berg- und Huttenwesen im Herzogthum Nassau.)
Published at Wiesbaden, 1863, p. 42 et seq.
Referred to in: Wagner's Jahresber., 1863, vol. IX, pp. 177, 178.

Plattner, C. F.
Vorlesungen über allgemeine Huttenkunde.
1863, Freiberg, vol. II pp. 344-358.

Rose, H.
On the production of nickel free from arsenic from "Kupfernickel" and so-called nickel speiss.
Zeits. analyt. Chemie, 1863, vol. I, pp. 420-425.
Abst., Dingler's Polytechn. Jour., 1863, vol. 167, p. 465.
Wagner's Jahresber., 1863, vol. IX, p 177

Thompson, L.
Process for the manufacture of pure metallic nickel. Process for the separation of cobalt and nickel.
Newton's, London Jour. of Arts, 1863, Feb., vol. XVII (N.S.), pp. 65-72.
Technologiste, Apr., 1863, p. 337 et seq.
Dingler's Polytechn. Jour., vol. 170, 1863, pp. 41-43, 206-208.
Wagner's Jahresbericht, 1863, vol. IX, pp. 175, 176.

1864—Anonymous.
On the production of nickel.
Berg- und Huttenmänn. Ztg., 1864, vol. 23, pp. 58-60.
Dingler's Polytechn. Jour., 1864, vol. 172, p. 364.
Wagner's Jahresbericht, 1864, vol. X, pp. 124-129.

Baker, Wm.
On the occurrence of nickel in lead, and its concentration by Pattinson's process.
Jour. Chem. Soc. (London), 1864, Nov., vol. II, pp. 377, 378.
Abst., Chem. News, 1864, vol X, pp. 233, 234.
Bull. Soc. Chim., 1865, II, p 156.
Dingler's Polytechn. Jour., 1865, vol. 175, pp. 36, 37.

Baucher.
Technical application of nickel.
Berg- und Hüttenmänn Ztg., 1864, vol. XXIII, pp. 91, 92.
Wagner's Jahresbericht, 1864, vol. X, pp. 129, 130.

1865—Anonymous.
Smelting of nickeliferous copper converter slags at the Altenau silver smeltery (Upper Harz), with a view to obtain nickel matte.
Berg- und Hüttenmänn Ztg., 1865, vol. 24, pp. 9, 10.
Wagner's Jahresbericht, 1865, vol. XI, pp. 173-176.

Böttger.
On the production of nickel in the Mansfield district.
Berggeist, 1865, vol. 20, No. 40.

Croddeck, A. von.
The working up of "Krätzkupfergranalien" to obtain nickel vitriol.
Berg- und Hüttenmänn Ztg., 1865, vol. XXIV, p. 146.
Abst., Wagner's Jahresber., 1865, vol. XI, pp. 172, 173.

Herter.
The production of nickel from "vitriols."
Berggeist, 1865, No. 30.
Abst., Wagner's Jahresber., 1865, vol. XI, pp. 171, 172.

Schnabel.
The production of copper-nickel from Nassau nickel ores, with particular reference to the operations as carried out at the Isabellen plant at Dillenburg.
Zeits. f. Berg-, Hutten- und Salinenwesen im preussischen Staate, 1865, vol. XIII, pp. 105-139.
Abst., Wagner's Jahresbericht, 1865, vol. XI, pp. 176-178.

1866—Müller.
The nickel-ore deposits of Rewdinsk, near Katherinenburg (Ural Mountains).
Paper read before the Bergmännische Verein zu Freiburg, Jan. 2, 1866.
Berg- und Hüttenmänn. Ztg., 1866, vol. 25, p. 65.

Schnabel.
Production of copper-nickel at the Isabellen smeltery near Dillenburg.
Berg- und Hüttenmänn. Ztg., 1866, vol. 25, pp. 234-236.

Wright, W.
Extraction of cobalt and nickel
Bull. Soc. Chim., 1866, vol. V (1st series), pp. 475, 476.

1867—Garnier, J.
Note on the geology of New Caledonia.
Paris, Bull. Soc. Geol., 1867, vol. XXIV, pp. 438-451.

Garnier, J.
Essay on the geology and mineral resources of New Caledonia.
Annales des Mines, 1867, vol. XII, pp. 1-92.

Hermann, R.
On rowdauskite, a new nickel ore, and the production of nickel from this ore.
Jour. prakt. Chemie, 1867, vol. 102, pp. 405-409.
Moscow, Bull. Soc. Nat., 1867, vol. 40 (pt. 1), pp. 554-558.
Abst, Wagner's Jahresbericht, 1868, vol. XIV, p 111, 112.

Kleinschmidt, J. L., St. Louis (Mo.).
On the production of nickel and cobalt.
Berg- und Hüttenmänn. Ztg., 1867, vol. XXVI, No. 6, pp. 45, 46.
No. 7, pp. 57-59, 94, 95, 130, 131, 147-149, 162-164.

Kripp, V.
Production of nickel and cobalt from copper ores containing silver.
Oesterr. Zeits. f. Berg- und Huttenwesen, 1867, No. 8.
Abst., Berg- und Huttenmänn. Ztg, 1868, vol. XXVII, p. 223.
Wagner's Jahresbericht, 1868, vol. XIV, pp. 111, 112.

Stromeyer, A.
On the manufacture of nickel.
Chem. News, 1867, vol. 16, No. 400, pp. 53, 54.

1868—Bredberg, B. G.
On nickel and its recovery from the ores. (Operation at the nickel-smeltery Klefva, Sweden.)
Metallurgisca Anteckningar Metallurgical observations (Sjette Häflet), Stockholm, 1868, 2rdr.
Abst., Berg- und Hüttenmänn. Ztg., 1868, vol. 27, No. 52, pp. 441-443

Flight, W.
On the chemical composition of a Bactrian coin of Euthydemos of the second century, B.C. (Ni-Cu alloy).
Paper read before the Numismatic Society.
Engineer (London), 1868, vol. XXVI, No. 671, p. 347.

Kerl.
** A practical treatise on metallurgy.
Adapted from the last German edition by W. Crookes and Röhrig, 1868, London.
Vol. I, Chapter IX: Nickel, pp. 554-583: Exhaustive synopsis of processes for the production of nickel.

1869—Anonymous.
The copper-nickel industry in the district of St. Blasien (Schwarzwald).
Berggeist, 1869, No. 89.
Abst., Berg- und Huttenmänn. Ztg., 1870, vol. 29, p. 387.

Garnier, J.
Geological sketch and mineral resources of New Caledonia.
St. Etienne, Bull. Soc. Industrie Minèrale, 1869-1870, vol. XV, pp. 301-320.

Stapff, F. M.
Notes on the Klefva nickel smeltery (Sweden).
Berg- und Huttenmänn. Ztg., 1869, vol. XXVIII, No. 13, p. 109 et seq.

1870—Anonymous.
Production of crude nickel.
Berggeist, 1870, No. 15.
Abst., Berg- und Hüttenmänn. Ztg., 1871, vol. 30, p. 102.
Statistical data.

Anonymous.
Statistical data on the production of nickel for 1868 and 1869 in Prussia, Saxony, Baden, Hungary, Salzburg, Norway and Sweden.
Wagner's Jahresbericht, 1870, vol. XVI, pp. 155, 156.

Anonymous.
Norwegian nickel plants.
Berggeist, 1870, No. 29.
Abst., Berg- und Hüttenmänn. Ztg., 1871, vol. 30, p. 114.

Wagner, R. (Würzburg.)
On the use of sodium nitrate in the metallurgy of nickel and copper.
Berg- und Hüttenmänn. Ztg., 1870, vol. XXIX, No. 16, pp. 133-135, 161, 189, 190.
Chem. News, 1870, vol. XXII, No. 559, p. 83.
Moniteur scientifique, 1870, Aug., p. 709.
Wagner's Jahresbericht, 1870, vol. XVI, pp. 151-155.

Wharton, J.
On two peculiar products in the nickel manufacture.
Amer. Jour. Science, 1870, vol. 49 (2nd series), pp. 365-368.
Chem. News, 1870, vol. XXI, No. 551, pp. 280, 281.
Dingler's Polytechn. Jour., 1870, vol. 197, p. 331.
Berg- und Hüttenmänn, Ztg., 1870, vol. 29, p. 336.

1872—Anonymous.
The largest nickel mine in the world (Mine-la-motte, Mo.).
Engng. Min. Jour., 1872, vol. XIV, No. 7, pp. 98, 99.

Engwelling.
The only nickel mine of the United States.
Mining & Scient. Press, 1872, Nov. 30, vol. XXV, No. 20.
Short note on the Gap (Lancaster) mine, Penn.

Watts, H.
A dictionary of chemistry and the allied branches of other sources.
1872, New York, vol. IV, pp. 33-35. Gives an account of the earliest attempts to produce nickel from speiss or roasted copper-nickel.

1873—Anonymous.
Nickel: Its production and application in the industry and for coinage purposes.
Hannover, Wochenbl. f. Handel und Gewerbe, 1873, No. 36.
Dingler's Polytechn. Jour., 1873, vol. 210, pp. 75-77.

Anonymous.
Nickel.—The Gap mine in Pennsylvania.
Correspondence to the New York "Times".
Reprinted in Engng. Min. Jour., 1873, vol. 16, No. 13, pp. 194, 195.
Berg- und Hüttenmänn. Ztg., 1874, vol. 33, pp. 11, 12.
Wagner's Jahresbericht, 1874, vol. XX, pp. 187, 188.

Courtis, W. M.
The Wyandotte silver smelting and refining works.
Trans. Amer. Inst. Min. Engrs., 1873, vol. II, pp. 89-101.
Engng. Min. Jour., 1873, vol. XVI, pp. 338-340.

Overman, Fr.
A treatise on metallurgy, comprising mining, and general and particular metallurgical operations.
1873, New York, D. Appleton & Co., 6th ed., pp. 623-630.

1874—Anonymous.
Mining and metallurgy of nickel.
Mining World (London), 1874, vol. XII.
Engng. Min. Jour., 1874, Nov. 14, vol. XVIII, pp. 309, 310.
Abst., Berg- und Hüttenmänn. Ztg., 1875, vol. 34, p. 58.

Künzel, C. (Blasewitz).
On the influence of a slight amount of chlorine upon the properties of certain metals (e.g., Ni-Cu alloys).
Berg- und Hüttenmänn. Ztg., 1874, vol. 33, pp. 6, 7.

Phillips, J. A.
** Elements of metallurgy.
A practical treatise on the art of extracting metals from their ores.
London, 1874, Ch. Griffin & Co., pp. 358-362.

Stölzel, Dr. C.
Mining and metallurgy at the International Exposition of Vienna, 1873.
(Report on nickel.)
Berg- und Huttenm. Ztg., 1874, vol. 33, p. 142.

Künzel, C.
Report on Nickel and its applications.
Amtlicher Bericht über die Wiener Ausstellung von, 1873.
Braunschweig, 1875, vol. III, part I, p. 859 et seq.
Abst., Wagner's Jahresbericht, 1875, vol. XXI, pp. 251-262.

1875—Winkler, Cl. A.
On the manufacture of large nickel or cobalt castings.
Ber. Sächs. Gesell. Wissenschaften, 1875, June 21, vol. 27, pp. 196-198.
Abst., Dingler's Polytechn. Jour., 1876, vol. 222, pp. 175-177.
Chem. News, 1877, vol. XXXV, No. 908, p. 166.
Wagner's Jahresbericht, 1877, vol. XXIII, pp. 214-216.
Annalen d. Physik u. Chemie, 1877, vol. I, pp. 293-296.

1876—Bell, R.
Rocks north of lake Huron, etc., Ontario.
Canada, Geol. Survey, 1876, pp. 294-297.

Christofle, P., and Bouilhet, H.
Treatment of certain nickel ores.
British Pat. No. 2519, June 17, 1876.
Abst., Ber. d. deutsch. Chem. Gesell., 1877, vol. X, p. 1911.

Christofle, P., and Bouilhet, H.
Metallic nickel extracted from the ores of New Caledonia.
Comptes- Rendus de l'Académie des Sciences, 1876, vol. 83, pp. 29-31.
Abst., Chem. News, 1876, vol. XXXIV, No. 871, p. 51.
Berg- und Hüttenmänn. Ztg., 1876, vol. 35, p. 272.
Wagner's Jahresbericht, 1876, vol. XXII, pp. 266, 267.

Garnier, J., Paris.
(Lake, W. R.).
Production of nickel from its ores.
British Pat. 1194, Mar. 20, 1876.
Abst., Ber. d. deutsch. Chem. Gesell., 1877, p. 1760.

Garnier, J.
The New Caledonian nickel mines.
Bull. Soc. d'Encouragement à l'Industrie Nationale, 1876, July, vol. III (3rd series), p. 412.
Moniteur Scientifique, 1876, No. 416, p. 857 et seq.

Jungck, M.
On the formation of graphite in nickel.
Dingler's Polytechn. Jour., 1876, vol. 222, pp. 94, 95.
Wagner's Jahresbericht, 1876, vol. XXII, pp. 268, 269.

Levitzky, M.
The nickel mine of Revda, Russia.
Revue Universelle, 1876, vol. 39, No. 3, pp. 679-681.
Berg- und Huttenm. Ztg., 1876, vol. 35, p. 308.
Wagner's Jahresbericht, 1876, vol. XXII, pp. 267, 268.

Mason, J., and Parkes, A.
Process for the treatment of ores and alloys of nickel.
U.S. Pat. 180142, July 25, 1876. British Pat. 2088, May 17, 1876.
Abst., Ber. deutsch. chem. Gesell., 1876, vol. X, p. 894; 1909.

Meissonier.
Existence in Spain of nickel-ore deposits similar to those of New Caledonia. (Province of Malaga.)
Comptes-Rendus, de l'Académie des Sciences, 1876, vol. 83, pp. 229, 230.
Chem. News, 1876, vol. XXXIV, No. 873, p. 72.

Parkes, A. (Graveley Hill, Birmingham).
Separation of nickel from its ores.
British Pat. 540, Feb. 10, 1876.
Abst., Ber. d. deutsch. Chem. Gesell., 1877, vol. X, p. 1758.

Typke, W.
On a new nickel mineral from New Caledonia.
Chem. News, 1876, vol. XXXIV, No. 884, pp. 193, 194.
Chem. Soc. (London) Jour., 1877, I, p. 285.

1877—André, E.
German Pat. 6048, Nov. 1, 1877.

Badoureau.
Memoir on the metallurgy of nickel.
Ann. des Mines, 1877, vol. XII (7th series), No. 5, pp. 237-340.
Transl. in: Berg- und Hüttenm. Ztg., 1878, vol. 37, pp. 185, 186, 205-207, 212-214, 228-230, 244-247, 259-261.
Abst., Wagner's Jahresbericht, 1878, vol. XXIV, pp. 215-239.
Chem. News, 1878, vol. XXXVII, No. 953, p. 94.
Iron, 1878, vol. XI, No. 266.

Garnier, J.
Note on the treatment of the oxidic nickel ore at the Septèmes smeltery.
Paris, Mém. Soc. Ingénieurs Civils de France, 1877, pp. 441-450.

Lundborg, H.
On the production of nickel.
Jern. Kentorets Annaler, 1876, No. 2.
Berg- und Hüttenm. Ztg., 1877, vol. 36, pp. 300-302.
Wagner's Jahresbericht, 1877, vol. XXIII, pp. 209-214.

1878—Dixon, W. A.
On the metallurgy of nickel and cobalt.
Jour. Royal Soc. New South Wales for 1878, vol. XII, pp. 127-131.

Garnier, J.
On garnierite.
Paris, Acad. Sciences, Comptes-Rendus, 1878, vol. 86, pp. 684-686.

Parkes, H.
Production of nickel from New Caledonian ores (pimelite, nickel-magnesium silicate).
British Pat. 910, 1877.
Abst., Ber. d. deutsch. Chem. Gesell., 1878, vol. XI, p. 420.
Wagner's Jahresbericht, 1878, vol. XXIV, p. 239.

Wharton, J.
Manufacture of large nickel or cobalt castings. (Reply to Cl. Winkler.)
Dingler's Polytechn. Jour., 1877, vol. 226, p. 551.

Allen, A. H.
Some recent improvements in the metallurgy of nickel.
Iron, 1878, vol. XI, No. 267, p. 231; No. 268, p. 265; No. 270, pp. 297, 298, 326.
Bull. Soc. d'Encouragement à l'Industrie Nationale, 1879, Jan., vol. VI (3rd series), pp. 32-50.
J. Royal Soc. Arts, 1878, vol. 26, pp. 243-250.

Bode, Fr.
Smelting of nickel-bearing pyrrhotite (Magnetkies) at Kragero (Norway).
Dingler's Polytechn. Jour., 1878, vol. 229, pp. 376, 377.

Dixon, W. A.
On the metallurgy of nickel and cobalt—Chemical News, 1878, vol. 38, No. 993, pp. 268-270.
Berg. und Huttenm. Ztg., 1879, vol. 38, pp. 395-397.
Iron, 1879, vol. 13, No. 321, p. 294.
Revue Universelle des Mines, etc., 1879, vol. VI, No. 2, pp. 519-524.

Eustis, W. E. C.
The nickel ores of Oxford, Quebec (Canada).
Engng. Min. Jour., 1878, vol. 25, No. 11, p. 187.
Paper read before the Amer. Inst. Min. Engrs. at Philadelphia, Feb. 28, 1878.
Abst., Berg- und Huttenm. Ztg., 1878, vol. 37, p. 403.

Gard, W. E.
Analyses of cast nickel, and experiments on the combining of carbon and silicon with nickel.
Amer. Jour. Sciences and Arts, 1878, vol. XIV (3rd series), pp. 274-277.
Dingler's Polytechn. Jour., 1878, vol. 227, p. 109.
Wagner's Jahresbericht, 1878, vol. XXIV, pp. 240, 241.

Garnier, J.
On garnierite.
Paris, Comptes-Rendus de l'Academie des Sciences, 1878, vol. 86, pp. 684-686.

Kupelwieser, Prof.
The metallurgy at the Exposition of Paris.
Berg- und Hüttenm. Ztg., 1878, vol. 37, pp. 341, 342.
(Short note on the production of nickel.)
Berg- und Hüttenm. Ztg., 1879, vol. 38, pp. 137, 138.

Laroche, and Pratt.
Production of nickel.
German Pat. 3505, Apr. 17, 1878.
Abst., Berg- und Hüttenm. Ztg., 1879, vol 38, p. 27.
Precipitation of nickel from an acid sulphate solution by oxalic acid, conversion of nickel oxalate into carbonate of sodium carbonate, conversion of carbonate into metallic nickel.
Wagner's Jahresbericht, 1879, vol. 25, pp. 235, 236.

Schweder, G. Ph.
On the smelting of sulphide nickel ores with particular reference to the chemical operations taking place.
Berg- und Hüttenm. Ztg., 1878, vol. 37, No. 45, pp. 377-379, 385-387, 393-395, 409-411, 421-423; 1879, vol. 38, pp. 17-20, 37-39, 64-66, 79-82, 105-107, 121, 122.
Abst., Wagner's Jahresbericht, 1879, vol. XXV, pp. 214-232.
Of great historical interest.

1879—Flechner, R.
Two designs for gas-fired furnaces (hearth-furnace for refining nickel speiss), gas-fired roasting furnace.
Dingler's Polytechn. Jour., 1879, vol. 231, pp. 248-251.
Berg- und Hüttenmänn. Ztg., 1879, vol. 38, p. 211 (with figs. 5-15, table VI).
Wagner's Jahresber., 1879, vol. XXV, pp. 232-235.

Flechner, R. (Salzburg).
Particularities of the occurrence and working conditions of the European nickel-ore deposits.
Dingler's Polytechn. Jour., 1879, vol. 232, pp. 256-264, 365-373.
Abst., Wagner's Jahresbericht, 1879, vol. XXV, pp. 209-214.

Fleitmann, Th.
On the manufacture of ductile nickel and cobalt, and the applications of these metals in a state of purity.
Ber. d. deutsch. Chem. Gesell., 1879, vol. XII, pp. 454, 455.
Chem. News, 1879, vol. 40, No. 1028, p. 67.
Wagner's Jahresbericht, 1879, vol. XXV, p. 237.

1880—Fleitmann.
Zinc-containing nickel.
Nickel oxide is reduced conjointly with a little zinc oxide, resulting in a nickel alloy containing up to 10% Zn which alloy is very tenacious, so as to allow its use as sheets or wire either in the cold or in the heat. When metallic zinc is added to a bath of molten nickel, the former evaporates.
German Pat. 9405.
Abst., Berg- und Hüttenm. Ztg., 1880, vol. 39, p. 171.

Anonymous.
Process for producing malleable nickel and in a state of varying degrees of hardness. (Garnier method.)
Revue Industrielle, 1880, p. 344.
Chem. Ztg., 1880, vol. V, No. 37, p. 604.

Donath, Ed.
On the metallurgy and volumetric estimation of nickel.
Dingler's Polytechn. Jour., 1880, vol. 236, pp. 327-336, 409-415, 480-486.
This paper is of great historical interest.

Fleitmann, A. (Iserlohn).
On the production of ductile and malleable nickel and cobalt.
Berg- und Hüttenm. Ztg., 1880, vol. 39, p. 171, pp. 176-178.
(Communication by Prof. C. Winkler with regard to above paper, same journal, p. 255.)
Wagner's Jahresbericht, 1880, vol. XXVI, pp. 161-164.

Garnier, J.
On a new process for obtaining malleable nickel and in a state of varying degrees of hardness.
Paris, Comptes-Rendus de l'Académie des Sciences, 1880, vol. 91, pp. 331-333.

Garnier, J.
On ductile nickel.
Le Technologiste, 1880, No. 142.
Berg- und Hüttenm. Ztg., 1881, vol. 40, pp. 6, 7.

Liversidge, A.
Notes upon some minerals from New Caledonia.
Proc. Royal Soc. of New South Wales, 1880, vol. XIV, p. 231-236.
Contains a few historical details on the discovery of nickel-bearing minerals in New Caledonia by Jules Garnier in 1864.

Winkler, Prof. Dr. C.
On ductile nickel.
Berg- und Hüttenm. Ztg., 1880, vol. 39, p. 87.
Dingler's Polytechn. Jour., 1880, vol. 236, p. 40.
Chem. Ztg., 1880, No. 16, p. 258.

Zincken, W.
The mineral wealth of European Russia.
Berg- und Hüttenm. Ztg., 1880, vol. 39, p. 423.
(A short note on nickel ores.)

1881—Boeddicker, G. A.
Remarks on the H. Wiggin process for the production of cobalt and nickel adapted to be rolled out or drawn into wires.
(Addition of 1½%-3% of Mn to a bath of molten nickel.)
Wagner's Jahresbericht, 1881, vol. XXVII, p. 69.

Careis.
Production of nickel and cobalt.
Wochenschrift, Vereins deutsch. Ing., 1881, No. 17, p. 143.
Abst., Berg- und Hüttenm. Ztg., v. 40, No. 23, pp. 215, 216.

Drouin, Alex. (Paris).
Process for ultilizing poor lead-ore waste.
British Pat. No. 3646, 1881.
Abst., J. Soc. Chem. Ind., 1882, vol. I, p. 236.
Fischer's Jahresbericht, 1883, vol. 29, p. 149.

Galbraith, Wm. (Sheffield).
Separation of nickel from its ores or compounds.
British Pat. No. 5366, 1881.
Abst., J. Soc. Chem. Ind., 1882, vol. I, p. 369.

Kollmann.
On the tensile strength and elongation of nickel.
Stahl u. Eisen, 1881, vol. I, No. 2, pp. 72, 73.
Abst., Berg- und Huttenm. Ztg., 1881, vol. 40, p. 376.

Martin, P. E., Sireuil (Charente).
Production of tungsten, chromium, titanium, cobalt or nickel sponge.
German Pat. No. 18303, June 1, 1881.
Abst., Fischer's Jahresbericht, 1882, vol. 28, p. 120.
Ber. d. deutsch. Chem. Gesellschaft, 1882, vol. XV, p. 2764.

Readman, J. G., Glasgow.
Process for obtaining cobalt, nickel, and manganese salts and oxides.
British Pat. 4486, 1881.
(Abst.), J. Soc. Chem. Ind., 1882, vol. I, p. 235.

1882—Anonymous.
Metallurgy of nickel.
Iron, 1882, Jan. 27, v. XIX, p. 68.

Anonymous.
The mechanical properties of malleable nickel.
Engng. Min. Jour., 1882, Mar. 11, vol. 33, No. 10, p. 134.

Anonymous.
Nickel in Oregon. (Douglas County.)
Min. Sci. Press, 1882, v. 44, No. 25, p. 416.
Abst., Berg- und Hüttenm. Ztg., 1882, vol. 41, p. 332.

Eustis, W. E. C., and Howe, H. M.
Contributions to the metallurgy of nickel and of copper.
(Thomson's nickel-extraction process.)
Trans. Amer. Inst. Min. Engrs., 1882, vol. X, pp. 305-309.
Abst., Engng. Min. Jour., 1882, July 15, v. 34, p. 32.
Berg- und Hüttenm. Ztg., 1884, vol. 43, p. 100.
Fischer's Jahresber., 1883, vol. 29, pp. 149, 150.

Garnier, J.
Purification of metals, such as iron, nickel and copper on a "false" basic, oxidizing hearth.
St. Etienne, Bull. Soc., Industrie Minérale, 1882, vol. XI, pp. 889-899.
Abst., Fischer's Jahresbericht, 1883, vol. 29, pp. 150, 151.
Stahl u. Eisen, 1883, vol. III, p. 516 et seq.
Berg- und Hüttenmänn. Ztg., 1883, vol. 42, p. 517.

Gilchrist, and Thomas.
Production of nickel from New Caledonia ores.
British Pat. 1690, 1882.
Berg- und Huttenm. Ztg., 1883, vol 42, p. 273.
Melting of crude nickel in a gas furnace provided with tuyeres for blowing in air or in a Bessemer furnace under addition of silica and lime to bring the impurities into the slag.

Huntington.
The metallurgy of nickel and cobalt.
Jour. Soc. Chem. Ind., 1882, vol. I, pp. 258, 259.
Abst., Engng. Min. Jour., 1882, vol. 34, No. 11, p. 136.

1883—Anonymous.
Nickel production from garnierite.
Allgem. met. Ztg., 1883, No. 9.
Berg- und Huttenm. Ztg., 1883, vol. 42, p. 277.

Anonymous.
The Prat and Laroche nickel extraction process.
Engng. Min. Jour., 1883, June 2, vol. 35, p. 317.
Oesterr. Zts. Berg- und Huttenwesen, 1883, v. 31, No. 28, p. 377.
Berg- und Hüttenmänn. Ztg., 1883, vol. 42, p. 562.

Anonymous.
Fleitmann's malleable nickel.
Wochenschr. Vereins deutscher Ing., 1883, No. 4.
Berg- und Hüttenm. Ztg., 1883, vol. 42, p. 124 .

Blake, W. P.
Nickel.
Mineral Resources of the United States, 1883-1884, pp. 537-543.

Blake, W. P.
Notes on the metallurgy of nickel in the United States.
Trans. Amer. Inst. Min. Engrs., 1883, vol. XI, pp. 274-281.
Iron, 1883, vol. 22, pp. 69, 70.
Chem. News, 1883, vol. 48, pp. 87-89.
Of great historical interest.

McCay, Leroy W.
Contribution to the knowledge of cobalt, nickel and iron sulphides
1883, Freiberg, 46 pp. (pamphlet).

Manhès, P. Lyons (France).
Production of cobalt and nickel matte.
A new or improved process for the treatment of sulphurous and arsenical compound ores containing nickel, cobalt, and other metals.
a) German Pat. 29006, Nov. 15, 1883.
b) British Pat. 5355, Nov. 13, 1883.
Abst.,
a) Berg. und Hüttenm. Ztg., 1885, vol. 44, p. 55.
b) J. Soc. Chem. Ind., 1885, vol. 4, p. 120.
Wagner's Jahresbericht, 1884, vol. 30, pp. 151, 152.

Readman, J. B. (Glasgow).
Extracting cobalt, nickel and manganese from their ores.
British Pat. 5359, Nov. 13, 1883.
Abst, J. Soc. Chem. Ind., 1884, vol. III, p. 524.
Wagner's Jahresbericht, 1884, v. 30, p. 152.

Selve, G., and Lotter, F. (Altona).
Production of nickel free from oxide.
German Pat. 25798, 1883.
Abst., Moniteur Scient., 1884, v. 26, p. 1120.
Wagner's Jahresbericht, 1884, vol. XXX, p. 152.

Société Anonyme "Fonderie de Nickel et Métaux Blancs," Paris.
Improvements in the manufacture of nickel and of cobalt, and of alloys of either of these metals with iron.
British Pat. 2243, 1883. German Pat. 29547.
(Abst.) J. Soc. Chem. Ind., 1884, vol. III, p. 32.
Fischer's Jahresbericht, 1885, vol. XXXI, p. 99.

1884—Anonymous.
Senjen nickel mine in Norway.
Trans. Royal Geol. Soc., Cornwall.
Abst., Berg- und Huttenm. Ztg., 1884, vol. 43, p. 227.

Anonymous.
Nickel: The ores of nickel; principal localities of nickel ore in America.
Min. Sci. Press, 1884, vol. 48, No. 14, p. 242; No. 15, p. 258.

Berndorfer Metallwarenfabrik in Berndorf.
Production of malleable, ductile nickel and cobalt in compact form.
German Pat. No. 28989, Jan. 15, 1884.
Abst., Ber. d. deutsch. Chem. Gesell., 1884, vol. XVII, p. 511.
Dingler's Polytechn. Jour., 1884, vol. 254, p. 315.

Fleitmann (Iserlohn).
Production of highly ductile castings from metals and metal alloys by the addition of magnesium alloys instead of magnesium.
German Pat. 28460, Feb. 7, 1884.
Abst., Fischer's Jahresbericht, 1884, v. 30, p. 154.
Ber. d. deutsch. Chem. Ges., 1884 (Ref.), v. XVII, p. 511.

Garnier, J.
Note on a new process of treatment of sulphide nickel and cobalt ores.
Mem. Soc. Ing. Civils de France, 1884, I, pp. 715-725.
Engng Min. Jour., 1883, vol. 36, p. 393.
Bull. Soc. de l'Industrie Minérale, 1885, vol. XIV, pp 126-131.

Herrenschmidt, H., Boudi (near Sydney, N.S.W.).
Improvements in the extraction of cobalt, nickel, and manganese from their ores, and of nickel from its ores, when such ores are found in a similar condition to those of New Caledonia.
British Pat. 12044, Sept. 5, 1884.
Abst., J. Soc. Chem. Ind., 1885, vol. IV, p. 287.

Hermite, E., Rouen (France).
Method for treating ores or scoria containing copper or nickel.
British Pat. 2157, Jan. 25, 1884.
Abst., J. Soc. Chem. Ind., 1885, vol. IV, p. 121.

Krupp, A., Bernsdorff (Austria).
An improved manufacture of nickel and cobalt from their ores.
British Pat., 1464, Jan. 15, 1884.
Abst., J. Soc. Chem. Ind., 1884, v. III, p. 261.

Selwyn, A. R. C.
Canada, Geol. Survey, Summary Report, 1884-1885, p. 2A.
Canada, Geol. Survey, 1884, "Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada."

1885—Aaron, Ch. H.
Process of precipitating nickel and cobalt from solutions containing the same (in the form of methyl-sulpho-carbonates).
U.S. Pat. 330,454, Nov. 17, 1885.

Balling, C. A. M.
Die Metallhuttenkunde Gewinnung der Metalle und Darstellung ihrer Verbindungen auf den Hüttenwerken.
1885, Verlag von J. Springer, pp. 562-585.

Hoffman, G. Christian.
Analyses of ores from Sudbury area.
Canada, Geol. Survey, 1885, pp. 19, 20M.

Mindeleff, D., San Francisco (Cal.).
A method and apparatus for extracting nickel and cobalt from ores containing them.
British Pat. 10491, Sept. 4, 1885.
(Abst.,) J. Soc. Chem. Ind., 1885, vol. IV, p. 746.

Neill, J. W.
Treatment of nickel-cobalt mattes at Mine la Motte, Mo.
Trans. Amer. Inst. Min. Engrs., 1885, vol. XIII, pp. 634-639.
Engng. Min. Jour., 1885, vol. 39, pp. 108, 109.

Porcheron, H.
The exploitation of nickel in New Caledonia.
Bull. Soc. de l'Industrie Minérale, 1885, vol. XIV (2nd series), No. 1, pp. 89-125.
Genie Civil, 1885, vol. VIII, pp. 88-90.

Selve, G., and Lotter, F. (Altona).
Method for obtaining nickel and cobalt free from oxides.
German Pat. 32006, 1885.
Abst., Fischer's Jahresberichte, 1886, vol. XXXII, p. 158.

Wiggin, H, Wiggin, H. A., Johnstone, A. S., and Wiggin, W. W. (Birmingham).
Improvements in the manufacture of nickel and cobalt.
British Pat. 3923, Mar. 27, 1885.
(Abst.) J. Soc. Chem. Ind., 1886, vol. V, p. 172.

1886—Croisille.
New Caledonian nickel mines. (Report on Thio mines.)
Annales des Mines, 1886, vol. X (8th Series), No. 6, pp. 609-611.
Abst., Berg- und Hüttenm. Ztg., 1887, vol. 46, p. 287.

Gautier, F.
The extraction of cobalt and nickel from manganiferous ores.
Génie Civil, 1886, vol. VIII, pp. 246, 247.
Fischer's Jahresbericht, 1886, v. 32, pp. 157, 158.

Pebal, L.
Nickel carbide in nickel obtained by the reduction of the oxide by charcoal at a white heat.
Liebig's Annalen d. Chemie, 1886, v. 233, pp. 160-165.
(Abst.), J. Chem. Soc. (London), 1886, v. 50, p. 854.

1887—Flechner, R.
Communications on nickel-ore deposits and production of nickel in general, with particular reference to nickel-ore mining in Schladming.
Oesterr. Z. Berg- und Hüttenwesen, 1887, v. 35, No. 6, pp. 63-68, and No. 7, pp. 80-84.
Abst., Berg- und Hüttenm. Ztg., 1887, v. 46, pp. 247, 248.

Leo.
Occurrence of nickel ores in Klefva (Sweden).
Zeitschr. d. Oberschles. Berg- u. Hüttenmänn. Vereins, 1887, May-June.
Abst., Berg. u. Hüttenm. Ztg., 1887, v. 46, No. 29, p. 282.

Levat, M.
Investigation into the nickel, cobalt and chromium ore deposits of New Caledonia.
Paper read, Sept. 29, 1887, before the French Assoc. for the Advancement of Sciences.
Comptes Rendus, 1887, vol. I, pp. 242, 243.

Mackintosh, J. B.
A crystalline subsulphide of iron and nickel.
Trans. Amer. Inst. Min. Engrs., 1887, vol. XVI, pp. 117, 118.
Chem. News, 1888, vol. 58, p. 200.

Warren, J. T. P.
The detection of adulteration of metallic nickel and other metals by the magnet.
Chem. News, 1887, vol. 55, p. 37.

1888—Attwood.
Origin of Sudbury ores, being a discussion of Bonney's paper.
Quart. Jour. Geol. Soc., London, 1888, vol. 44, pp. 834-838.

Bonney, T. G.
Notes on a part of the Huronian series in the neighbourhood of Sudbury (Canada).
Quart. Jour. Geol Soc., London, 1888, vol. 44, pp. 32-44.

Collins, J. H.
On the Sudbury copper-deposits.
Quart. Jour. Geol. Soc., London, 1888, v. 44, pp. 834-838.

Deutsche Gold- und Silberscheide Anstalt vorm. Rössler.
Process for extracting nickel and cobalt from waste lyes.
German Pat. 45193, May 3, 1888.
(Abst.) Ber. d. deutscher Chem. Gesell., 1888 (Ref.), vol. XXI, p. 904.
Fischer's Jahresbericht, 1888, vol. XXXIV, p. 294.

Heard, J., Jr.
New Caledonia nickel and cobalt.
Engng. Min. Jour., 1888, v. 46, No. 6, p. 103.
Abst, Berg- und Hüttenm. Ztg., 1888, v. 47, p. 461.

Herrenschmidt, H., and Capelle, E.
Cobalt and nickel: their industry.
Moniteur Industriel, 1888, May 3, 10, 17, 24.

Langguth, W.
Treatment of cobalt and nickel ore in a converter.
Min. Sci. Press, 1888, Feb. 18, v. 55, p. 102.

Manhès, P., Lyons (France).
Improved method of extracting nickel and cobalt from ores or compounds and apparatus therefor.
British Pat. 17410, Nov 29, 1888; German Pat. 47444, 1888.
(Abst) J. Soc. Chem. Ind., 1889, vol. VIII, p. 988.
Berg. und Huttenm. Ztg., 1889, v. 48, No. 28, p. 252.
Fischer's Jahresbericht, 1889, vol XXXV, p. 268.

Merritt, W. H.
The minerals of Ontario and their development.
Trans Amer Inst. Min. Engrs., 1888, vol. XVII, pp. 293-300.

Selwyn, A. R. C.
Nickel copper deposits at Sudbury.
Canada, Geol. Survey, 1887-1888, part I, p. 59A.

1889—Clarke, F. W., and Catlett, Ch.
A platiniferous nickel ore from Canada.
Amer. Jour. Science, 1889, vol. XXXVII, pp. 372-374.

Peters, E. D.
The Sudbury ore deposits.
Trans. Amer. Inst. Min. Eng., 1889-1890, vol. XVIII, p. 278.

Kruss, G.
Method for decomposing commercial nickel and its salts into pure nickel.
German Pat. 48547, Jan. 12, 1889.
(Abst.) Fischer's Jahresbericht, 1889, vol. XXXV, p. 267.

Selwyn, A. R. C.
Minerals in Huronian rocks, Ontario.
Canada, Geol. Survey, 1889, p. 5A.

Natusch, C. W. B.
Production of nickel and cobalt.
German Pat. 52035, Oct. 30, 1889.
Abst., Berg- und Hüttenmänn. Ztg., 1890, v. 49, p. 250.
Z. angew. Chemie, 1890, vol. III, p. 337.
Fischer's Jahresbericht, 1890, vol. XXXVI, p. 338.
Chem. Ztg., 1890, vol. XIV, No. 47, pp. 770, 771.

Ostermann.
Method of demagnetizing nickel. (Alloy of nickel with 10-15% chromium.)
German Pat. 48622.

Peters, E. D., Jr.
The nickeliferous chalcopyrite and pyrrhotite deposits of Sudbury, Ontario.
Trans. Amer. Inst. Min. Engrs., 1889, v. 18, pp. 278-289.
Berg- und Hüttenm Ztg., 1891, v. 50, pp. 149, 150.

Stenbock, M.
Nickel ores in the Ural (Russia).
Chem. Ztg., 1889, v. 13, No. 27, p. 429.
Abst., Berg- und Hüttenm. Ztg., 1889, v. 48, p 171.
J. Soc. Chem. Ind., 1889, vol. VIII, p. 399.

Vogt.
Nickel matte production at Skjäkerdal from nickeliferous pyrrhotite.
Dingler's Polytechn. Jour., 1889, v. 272, pp. 322, 323.
Berg- und Hüttenm. Ztg., 1889, v. 48, No. 24, p. 216.

1890—Anonymous (E. B.).
New Caledonia nickel. (Translated from the French edition.)
Sidney, 1890, 31 pp. Pamphlet giving the early detailed history of the discovery and development of the New Caledonian nickel ore deposits.

Anonymous.
New process for smelting nickel and cobalt ores.
(Natusch-Schoeneis process.)
Chem. Ztg. 1890, vol. XIV, p. 1475

Barlow, A. E.
Relation of granites to Huronian rocks, Ontario.
Am. Geologist, vol. 6, 1890, pp. 19-32.

Bell, R.
Report of the Royal Commission on the Mineral Resources of Ontario, 1890.
Relation of granites to Huronian rocks, Ontario.
Bull. Geo. Soc. Am., 1890, vol. II, pp. 125-137.

Blomeke, C.
On the occurrence and production of tin, *nickel*, platinum and mercury in the world.
Berg- und Hüttenmänn. Ztg., 1890, v. 49, No. 27, p. 238.

Garnier, J., Paris.
Process for the manufacture of metallic nickel, together with alloys of nickel with iron, etc.
British Pat. 17623, Nov. 3, 1890.
(Abst.)
Berg- und Hüttenm. Ztg., 1892, v. 51, p. 266.
J. Soc. Chem. Ind., 1891, v. 10, p. 1010.
Fischer's Jahresbericht, 1892, v. 38, pp. 200, 201.

Clarke, F. W.
Some nickel ores from Oregon.
Bull. 60, U.S.G.S., 1890, pp. 21-26.

Kosmann, B.
The nickel ores of Frankenstein (Lower Silesia).
Berg- und Hüttenm. Ztg., 1890, v. 49, No. 13, pp. 111-113.

Mond, L., Winington Hall, Northwich.
Compound of nickel and carbonic oxide and process of manufacturing the same.
Can. Pat. 35427, Nov. 18, 1890 (5 yrs.).
Can. Pat. Off. Rec., 1890, v. 18, p. 568.

Mond, L., Winington Hall, Northwich (England).
Manufacture of nickel.
Can. Pat. 35428, Nov. 18, 1890 (5 yrs.).
Can. Pat. Off. Rec., 1890, vol. XVIII, p. 568.

Mond, L., Langer, C., and Quincke, Fr.
** Action of carbon monoxide on nickel.
J. Chem. Soc. London (Trans.), 1890, v. 57, pp. 749-753.

Mond, L., Northwich.
Improvements in the manufacture of nickel.
British Pat. 12626, Aug. 12, 1890.
(Abst.) J. Soc. Chem. Ind., 1891, vol. X, p. 774.
Same as German Pat. 57320, 1890, Abstr. in Fischer's Jahresbericht, 1891, vol. 37, pp. 210, 211.

Moore, Th.
New Caledonian nickel ores.
Chem. News, 1890, vol. 62, p. 180.

Parker, J.
British Pat. No. 5199, Apr. 3, 1890.
Abst., Berg- und Hüttenmänn. Ztg., 1891, vol. 50, p. 447.

1891—Anonymous.
Extraction of cobalt and nickel from manganiferous cobalt ores.
(Process used by the Société de Produits Chimiques, Etablissements Malétra.)
Iron, 1891, vol. 38, p. 402.
Fischer's Jahresbericht, 1891, vol. 37, p. 210.

Barlow, A. E.
The nickel and copper deposits of Sudbury.
Ottawa Naturalist, June, 1891: read March 6, 1891, before the Logan Club, Ottawa.
The nickel and copper deposits of Sudbury.
Canada, Geol. Survey, 1890, 1891, vol. V, pp. 122-138S.

Bell, R.
Report on the Sudbury Mining District (1888-1890).
Canada, Geol. Survey Annual Report, 1890-1891, vol. V, Report F, pp. 1-95.

Bell, R.
The nickel and copper deposits of Sudbury District, Canada.
Reprint from Bulletin of the Geological Soc. America, 1891, v. II, pp. 125-140.

Bell, R.
Ontario, Report Bureau of Mines, 1891, vol. I, pp. 88-90.

Berthelot, M.
A volatile compound of iron and carbon monoxide.
On nickel carbonyl.
Comptes-Rendus de l'Académie des Sciences, 1891, vol. 112, pp. 1343-1349.
Abst., Berg- und Hüttenmänn. Ztg., 1891, v. 50, p. 361.
J. Chem. Soc. (London), 1891, v. 60-II, p. 1427.

Ditte, Alfred.
Lecons sur les métaux.
(Professées à la Faculté de Sciences de Paris.)
1891, Paris Vve Ch. Dunod, Editeur, vol. II, pp. 56-80.

Frémy, M.
** Encyclopédie chimique.
Tome V, 2e section, 2e partie: Nickel et cobalt, nar. A. M. Villon.
(1891, Paris, Vve Ch. Dunod, Editeur), 85 pp.

Garnier, J.
Memoir on the nickel, copper and platinum mines of the Sudbury district (Canada).
Mémoires de la Société des Ingénieurs Civils de France, 1891, March, vol. I, pp. 239-259.

Garnier, J.
On the volatilization of iron and nickel by carbon monoxide (nickel carbonyl).
Comptes-Rendus de l'Académie des Sciences, 1891, vol. 113, pp. 189-191.

Gilchrist, P. C.
The basic process as applied to copper smelting.
J. Soc. Chem. Ind., 1891, vol. 10, pp. 4-16.

Herrenschmidt, H. L.
Petit Quevilly, près Rouen (France).
Improvements in the treatment of certain mattes or ores for the separation of nickel and cobalt from copper.
British Pat. 14290, Aug. 24, 1891.
(Abst.) J. Soc. Chem. Ind., 1892, vol. XI, p. 694.

Martins, F. W. (Sheffield).
Improvements in the manufacture of alloys of nickel and copper, and of alloys of nickel and iron, and of alloys of nickel, copper and iron.
British Pat. 19191, Nov. 6, 1891
(Abst.) J. Soc. Chem. Ind., 1892, vol. XI, p. 822.

Mond, Ludwig, London.
Process of making compounds of nickel and carbon monoxide.
U.S. Pat 455,227.
Process of obtaining metallic nickel. U.S. Pat. 455,228.
Compound of nickel and carbon monoxide. U S. Pat. 455,229.
Process of depositing nickel. U.S. Pat. 455,230. All of June 30, 1891.

Mond, L.
On nickel carbon oxide and its application in arts and manufactures.
British Assoc. Annual Meeting, Section B, Report for 1891, pp. 602-607.
(Abst.) J. Soc. Chem. Ind., 1891, vol. X, p. 836.

Parker, T., and Robinson, E.
Improvements in the treatment of solutions containing nickel and iron for the obtainment of useful products therefrom.
British Pat. 14159, Aug. 21, 1891.
Abst, J. Soc. Chem. Ind., 1892, vol. XI, p. 755.

Pelatan, L.
New process for the treatment of the cobalt ores from New Caledonia.
Genie Civil, 1891, vol. XVIII, pp 373, 374. (Plate XXXIV.)

Peters.
Modern American methods of copper smelting. The smelting of the pyritic Sudbury ores.
2nd ed., p. 291 et seq. New York, 1891.
Berg- und Huttenm. Ztg., 1892, vol. 51, pp. 172, 173.
Z. angew. Chemie, 1892, vol. V, p. 338.

Roberts-Austen, W C.
An introduction to the study of metallurgy.
1891, London, pp. 268-271: Wet process of treating nickel and cobalt ores.

Roscoe, H. E., and Schorlemmer, C.
A treatise on chemistry.
1891, New York, vol. II,—Metals, part, II, pp. 143-145.

Schützenberger.
Volatility of nickel on treatment with dry hydrochloric acid gas.
Engng. Min. Jour., 1891, vol. 52, No. 10, p. 263.
Berg- und Hüttenm. Ztg., 1891, vol. 50, p. 391.

Sella, A.
Native nickel in river sand near Biella (Piedmont).
Comptes-Rendus de l'Académie des Sciences, 1891, vol 112, pp. 171-173.
J. Chem. Soc. (London), 1891, vol. 60, 1, p. 526.

Stahl, W.
Nickeliferous copper refining slags.
Berg- und Hüttenm. Ztg., 1891, vol. 50, No. 29, pp. 269-271.

Strap, J., Paris (France).
Process for the separation of copper, nickel and silver from mattes or alloys containing the same, and the treatment of the residues resulting therein.
British Pat. 4396, Mar. 11, 1891.
(Abst.) J. Soc. Chem. Ind., 1892, vol. XI, p. 616.
Fischer's Jahresbericht, 1892, vol. 38, p. 209.

Vogt, J. H. L.
Differentiation in a dike in the Christiania district, Norway.
Trans. Geol. Soc., in Stockholm, 1891, No. 138, vol. XIII, part V, May, pp. 476-536.
(See review of this paper by J. J. H. Teall, Geol. Mag., London, Feb., 1892.)

Williams, G. H.
Microscopical character of Sudbury rocks.
Canada, Geol. Survey, 1890, 1891, vol. V, part F, pp. 55-82.

Nickel and copper.
Ontario, Second report of the Bureau of Mines, 1892, pp. 129-148.

1892—Anonymous.
Furnaces for the production of nickel in Canada. (Herreshoff type.)
Berg- und Hüttenm. Ztg., 1892, vol. 51, No. 21, p. 186.
(Figs. 1-3, plate III.)

Anonymous.
A nickel-ore smelting plant for New Caledonia.
Engng. (London), 1892, vol. 53, pp. 288, 289 (5 figs.).
Abst., Engng. Min. Jour., 1892, vol. 13, p. 353.
Berg- und Huttenmänn. Ztg., 1892, vol. 51, p. 185.

Barlow, A. E.
Geology.
Am. Jour. Sci, 3rd Ser., 1892, vol. 44, pp. 236-239.

Basse and Selve.
Separation of iron, cobalt and zinc from nickel.
German Pat. 64251, of 1892.
Berg- und Huttenmänn. Ztg., 1893, vol. 52, pp. 90, 91.
Fischer's Jahresbericht, 1892, vol. 38, pp. 208, 209.

Benoit, F.
The New Caledonia nickel mines.
Bulletin de la Société de l'Ind. Minerale, 1892, vol. VI (3rd Series), pp. 753-804.

Berthelot, M.
Nickel carbonyl.
Bull. Soc. Chim., 1892, vol. XIII, pp. 431-434.
(Abst.) Jour. Soc. Chem. Ind., 1892, vol. XI, p. 909.

Bjoerkkman.
On the production of nickel.
Teknisk Tidskrift, 1892, p. 275.
(Abst.) Berg- und Hüttenmänn. Ztg., 1893, vol. 52, pp. 116, 117.
Fischer's Jahresbericht, 1893, vol. 39, pp. 281, 282.

Clarke, F. W., and Catlett, Ch.
A platiniferous nickel ore from Canada.
U.S. Geological Survey, 1892, Bulletin No. 64, pp. 20, 21.
Chem. News, 1893, vol. 67, pp. 53, 54.

Coppet, J. de, Paris (France).
Method of treating minerals, mattes, speiss, or other substances containing nickel.
U.S. Pats. No. 486594, 486595, both of Nov. 22, 1892.

Coppet, J. de, Paris.
Method of treating minerals containing nickel.
U.S. Pat. 484875, Oct. 25, 1892.

Coppet, J. de, Paris (France).
Production of nickel and cobalt from Cu-containing mattes.
British Pat. 4997, Mar. 14, 1892. German Pat. 64916.
Abst., Berg- und Hüttenmann. Ztg., 1893, vol. 52, p. 66.
J. Soc. Chem. Ind., 1893, vol. XII, p. 274.

Edison, T. A., Llewellyn Park.
Method of magnetic-ore separation applicable to nickeliferous pyrrhotite.
U.S. Pat. 485842, Nov. 8, 1892.

Emmens, St. H.
The nickel deposits of North Carolina.
Engng. Min. Jour., 1892, Apr. 30, vol. 53, pp. 476, 477.

Emmens, St. H.
Some new nickel minerals.
J. Amer. Chem. Soc., 1892, vol. XIV, pp. 205-211.

Emmens, St. H.
The constitution of nickeliferous pyrrhotite.
Jour. Amer. Chem. Soc., 1892, vol. XIV, pp. 369-375.

Foullon, H. B., von.
On some nickel-ore deposits.
Jahrbuch d. K.K. Geolog. Reichsanstalt, 1892, vol. 42, Heft No. 2, pp. 223-310.

Herrenschmidt, H.
Separation of nickel or cobalt from copper.
German Pat. No. 62856 of 1892.
Abst, Fischer's Jahresbericht, 1892, vol. 38, p. 208.
Z. angew. Chemie, 1892, vol. V, p. 367.

Herrenschmidt, H. L.
Process for the production of nickel.
German Pat. 68559.
Abst., Z. angew. Chemie, 1893, vol. VI, pp. 293, 294.
Berg- und Hüttenmann. Ztg., 1893, vol. 52, p. 234.
Fischer's Jahresbericht, 1893, vol. 39, p. 281.

Hoffman, G Ch.
Chemical contributions to the geology of Canada from the laboratory of the Survey.
Canada, Geolog. Survey Annual Report, 1892-1893, New Series, vol. VI, pp. 37R-43R.

Hopkinson, J.
Note on the density of nickel and iron.
Proc. Royal Soc., 1892, vol. 50, pp. 212-222.

Ingalls, W. R.
Nickel and cobalt.
Mineral Industry, 1892, vol. I, pp. 343-351.
The metallurgy of nickel (by Emmens, St. H.).
pp. 352-356; the Orford Nickel process (by R. M. Thompson), pp. 357, 358.

Ingalls, W. R.
Nickel. (Mining and production in the United States.)
Engng. Min. Jour., 1892, vol. 53, pp. 40, 41, and pp. 62, 63.
Berg- und Hüttenmann. Ztg., 1892, vol. 51, pp. 62, 63.

Levat, D.
Memoir on the progress of the metallurgy of nickel and the recent applications of this metal.
Annales des Mines 1892, vol. I (9th series), No. 2, pp. 141-224.
(Abst.) Berg- und Huttenmänn. Ztg., 1892, vol. 51, No. 15, pp. 137-139.
Proc. Inst. Civil Engrs., 1892, vol. 110, pp. 54-60.
J. Soc. Chem. Ind., 1892, vol. XI, p. 920.
Fischer's Jahresbericht, 1892, vol. 38, pp. 201-208.

Macfarlane, T., Ottawa.
Process of extracting nickel from ores.
U.S. Pat. 484033, Oct. 11, 1892.

Remmler, H., Krüss, G., and Schmidt, F. W.
Determination of the atomic weight of nickel.
Z. anorg. Chemie, 1892, vol. II, pp. 221-234; pp. 235-254.

Strap, J. (Paris).
A process for recovering copper and nickel from ores or mattes containing these metals.
British Pat. 16800, Sept. 20, 1892.
(Abst.) J. Soc. Chem. Ind., 1893, vol. XII, p. 844.

Vogt, J. H. L. (Christiania).
Occurrence and production of nickel.
Nikkelforekonster og nikkel produktion, Kristiania, 1892, 80 pp.
(Pamphlet) published by the Norges Geologiske. Undersögelse, Christiania, 1892.
Abst., Berg- und Hüttenmänn. Ztg., 1893, vol. 52, pp. 13-15.
(Numerous foot-note references to B. H. Ztg.)

Wedding.
Iron-nickel alloys.
Verh. Vereins z. Beförd. Gewerbefleisses (Berlin), 1892, p. 52.
Abst., Berg- und Hüttenmänn. Ztg., 1893, vol. 52, pp. 149, 150.

1893—Nickel.
Mineral Industry, 1893, vol. II, pp. 475-480.

Anonymous.
A review of the metallurgical nickel-extraction processes.
I. Production of nickeliferous intermediary products.
Berg- und Hüttenmänn. Ztg, 1893, vol. 52, No. 15, pp. 121-123.

Adams, Frank D.
Geology of a portion of central Ontario, including description of nickeliferous pyrrhotite
Canada, Geol. Sur., 1892-1893, vol. VI, part I, pp. 1-15J.

Argall, Ph.
Nickel: The occurrence, geological distribution and genesis of its ore deposits.
Colorado Scien. Soc. Proc., 1891-1893, vol. IV, pp. 395-420; discussion pp. 420, 421.
(Reprinted in pamphlet form.)

Austin, W. L.
Nickel.
Part I. Historical sketch.
Colorado Scien. Soc. Proc., 1891-1893, vol. IV, p. 373.

Barlow, A. E.
Relation of granites to Huronian rocks north of Lake Huron, Ontario.
Bull. Geol. Soc. America, 1893, vol. IV, pp. 313-332.

Bartlett, C. C. (New Brighton, N. J.)
Improvements in the production and separation of sulphide of nickel from ores of nickel and copper.
U.S. Pat. 499314, June 13, 1893. British Pat. 11581, June 13, 1893.
(Abst.) J. Soc. Chem. Ind., 1893, vol. XII, p. 1041.

Browne, D. H.
The composition of nickeliferous pyrrhotite.
Engng. Min. Jour., 1893, vol. 56, pp. 565, 566.

Browne, D. H.
The exhibit of the Canadian Copper Company.
Engng. Min. Jour., 1893, vol. 56, pp. 289-291.

Charleton, A. G.
** Nickel: Its history, uses and distribution.
J. Roy. Soc. Arts, 1893-1894, vol. 42, pp. 496-511; discussion, pp. 511-513.

Coleman, A. P.
Rocks of Clear lake, near Sudbury.
Can. Record of Science, April, 1893, p. 344.

Emmons, S. F.
Geological distribution of the useful metals in the United States.
Trans. Amer. Inst. Min. Engrs., 1893, vol. XXII, pp. 69-71.

Foullon, H. B., von.
Origin of Sudbury ore bodies.
Trans. Am. Inst. Min. Eng., 1893, vol. XXIII, p. 330.

Fuchs, Ed., and Launay, L. de.
Traité des gites minéraux et métallifères.
Paris, 1893, vol. II, pp. 41-76.

Garland, J.
On nickel mining in New Caledonia.
Inst. of Mining & Metallurgy Trans., 1893, 1894, vol. 2, pp. 121-134.
Discussion, pp. 134-148.

Goodwin, W. L.
Nickeliferous pyrite.
Can. Record of Sci., April, 1893.

Hoepfner, C. (Giessen).
Improvements in the electrolytic production of nickel and other metals.
British Pat. 13336, July 8, 1893.
(Abst.) J. Soc Chem. Ind., 1894, vol. XIII, p. 744.

Klockmann.
Occurrence of nickel ores near Goslar (Harz.).
Zeits. f. prakt. Geologie, 1893, vol. I, No. 10, pp. 385-388.
Berg- und Huttenmánn. Ztg., 1893, vol. 52, pp. 388, 389.

Kosmann.
Nickel ores from Kosemütz, near Frankenstein (Silesia).
Sitzungsber. d deutsch. geolog. Ges., 1893, May 4.
Abst., Berg- und Hüttenmänn. Ztg., 1893, vol. 52, p. 265.

Levat, D.
Occurrence of Sudbury ores.
Can. Mine and Mech. Review, 1893, Aug., p. 138.

Moissan, H.
Rapid preparation of chromium, manganese, nickel and cobalt at high temperatures.
Comptes-Rendus de l'Académie des Sciences, 1893, vol. 116, pp. 349-351.

Penfield, S. L.
Pentlandite from Sudbury.
Am. Jour. Sci., 1893, vol. 45, p. 493.

Posepny, F. (Vienna).
The genesis of ore-deposits.
Metamorphous deposits in crystalline schists and eruptive rocks.
(Sudbury, Canada.)
Trans. Amer. Inst., Min. Engrs, 1893, vol. XXIII, pp. 329, 330.

Ricketts, P. de P.
Process of separating metallic nickel.
U.S. Pat. 505846, Oct. 3, 1893.

Thompson, R. M.
Process of obtaining and separating sulphide of nickel.
U.S. Pats. 489574-489576, all of Jan. 10, 1893.

Thomson, J. L., Bayonne.
Improvements in or relating to obtaining and separating sulphide of nickel in the treatment of mattes containing copper, nickel, iron, and other metals.
British Pat. 498, Jan. 10, 1893.
(Abst.) J. Soc. Chem. Ind., 1893, vol. XII, p. 451.

Thompson, R. M.
Improvements in or relating to obtaining and separating sulphide of nickel for use in metallurgical operations in the treatment of mattes, of copper, nickel, iron and other metals.
British Pat 499, Jan. 10, 1893.
(Abst.) J. Soc. Chem. Ind., 1893, vol. XII, p. 451.

Thompson, R. M, Assignor to the Orford Copper Co.
Method of obtaining sulphide of nickel.
Canadian Pat. 44723, Nov. 17, 1893.
Can. Pat. Office Record, 1893, vol. XXI, p. 937.

Thompson, R M., New York.
Process for the production of nickel sulphide from nickeliferous ores.
German Pat. 91288, Jan 11, 1893.
Abst., Berg- und Huttenmánn. Ztg., 1897, vol 56, p. 413.
Z, angew. Chemie, 1897, vol. 10, No. 12, pp. 376, 377.

Thomson, J. L., Bayonne, Assignor to the Orford Copper Co., N.J.
Method of producing and separating sulphide of nickel.
U.S. Pat. 489882, Jan. 10, 1893.

Vaughan, H. W. E.
The Metallurgy of Nickel. (Letter to the editor.)
Engng. & Min. Jour., 1893, vol. 56, p. 28.
Reply to above letter from R. M. Thompson, ibid, p. 51.
Reply to Thompson's letter by H. W. E. Vaughan, p. 133.

Vogt. J. H. L.
The formation of ore bodies in a basic eruptive magma by the differentiation process.
Zeits. f. prakt. Geologie, 1893, vol. I, pp 4-11; pp. 125-143, 257-284.
A very complete paper on the genesis of nickel-ore deposits, with many foot-note references.

Vogt, J. H. L.
The Canadian nickel industry. (Bessemerization of nickel matte.)
Pamphlet reprinted from a paper published in the "Nyt. Magazin for Natur videnskaberne Christiania, 1893."
Abst., Berg- und Huttenmánn. Ztg., 1894, vol. 53, pp. 93, 94.
Stahl u. Eisen, 1894, vol. 14, pp. 23-26.
J. Soc. Chem. Ind., 1894, v. 13, p. 400.
Fischer's Jahresbericht, 1894, vol. 40, pp. 249, 250.

1894—Adams, F. D.
On the igneous origin of certain ore deposits.
Jour. General Mining Assoc. of the Prov. Quebec, 1894-1895, vol. II, pp. 35-53.

Nickel.
Mineral Industry, 1894, vol. III, pp. 456-458.
The treatment of pyritous ores containing copper and nickel by Titus Ulke, p. 459.

Anonymous.
Desulphurization
The action of iron sulphide on manganese, aluminium, *nickel*, chromium, etc. (Discussion by various investigators)
Bull. Soc. Chim., 1894, vols. XI, XII, pp. 583-587.
(Abst.) J. Soc. Chem. Ind., 1894, vol. XIII, pp. 1063, 1064.

Anonymous.
Nickel in Silesia.
Engng. Min. Jour., 1894, vol. 57, No. 22, p. 514.

Bush, E. R.
The Sudbury nickel region.
Engng. Min. Jour., 1894, vol. 57, pp. 245, 246.

Donath, Ed.
On the recent results of chemical research in its relation to metallurgy.
(Nickel carbonyl.)
Oesterr. Zeits. f. Berg- und Hüttenwesen, 1894, v 42, No. 28, pp. 334-336.

Fleitmann, R.
Method for obtaining ductile nickel, or in a state adapted to be rolled out.
German Pat. 75848. (Abst.) Z. angew. Chemie, 1894, vol. VII, p. 405.
Fischer's Jahresbericht, 1894, vol. 40, p. 246.

Fleitmann, R.
Process for the production of malleable and ductile nickel.
German Pat. 73423. (Abst.) Berg- und Huttenmänn. Ztg., 1894, v. 53, p. 165.
Z. angew. Chemie, 1894, vol. VII, p. 170.
Fischer's Jahresbericht, 1894, v. 40, p. 245.

Garland, J.
On nickel mining in New Caledonia.
Trans. Inst. Mining & Metallurgy, 1894, vol. II, pp. 121-148.

Garnier, J.
L'aluminium et le nickel.
Paper read before the Association Francaise pour l'Avancement des Sciences, reprinted in 1895 from the "Revue Scientifique" of Mar. 23, 1894, in pamphlet form, 30 pp. Very important source for historical documentation.

Hoffman, G. Chr.
Report of the section of chemistry and mineralogy.
Canada, Geol. Survey, Annual Report, 1894, vol. VII (New Series), pp. 20R, 21R, 938-958.

Höpfner, C., Giessen (Germany).
Improvements in the electrolytic production of nickel and other metals.
British Pat. 13336, July 8, 1884.
Abst., J. Soc. Chem. Ind., 1894, v. 13, p. 744.

Hoepfner, C., Giessen (Germany).
An improved process or method for the treatment of ores of nickel or cobalt.
British Pat., 11307, June 11, 1894.
Abst., J. Soc. Chem. Ind., 1895, v. 14, p. 754.

Kemp, J. F.
The nickel mine at Lancaster Gap, Pennsylvania, and the pyrrhotite deposits at Anthony's Nose, on the Hudson.
Trans. Amer. Inst. Min. Engrs, 1894, v. XXIV, pp. 620-633.

Manhès, P., Lyons (France).
Improvements relating to the treatment of nickel and cobalt ores.
British Pat. 6984, Apr. 7, 1894. (Abst.) J. Soc. Chem. Ind, 1895, v. XIV, p. 581.

Manhès, P., Lyons (France).
Improvements relating to the manufacture of nickel and cobalt.
British Pat. 6914, Apr. 6, 1894.
Abst., J. Soc. Chem. Ind., 1895, vol. XIV, p. 581.

Manhès, P., and Société Anonyme de Métallurgie du Cuivre.
Process for the production of cobalt and nickel.
German Pat. 47427.
(Abst.) Z. angew. Chemie, 1894, v. VII, No. 21, pp. 649, 650.
Fischer's Jahresbericht, 1894, v. 40, pp. 246-248.

Manhès, P., and Soc. Anonyme de Métallurgie du Cuivre.
Process for the treatment of nickel sulphide or crude nickel.
German Pat. 80467.
Abst., Berg- und Hüttenmänn. Ztg., 1895, v. 54, p. 221.
Oesterr. Zeits. f. Berg- und Hüttenwesen, 1895, v. 43, No. 24, p. 323.
Z. angew. Chemie, 1895, v. 8, pp. 197, 198.
Fischer's Jahresbericht, 1895, v. 41, pp. 195, 196.

Merritt, W. H.
Origin of Sudbury ores.
Trans. Am. Inst. Min. Eng., 1894, vol. XXIV, pp. 755, 756.

Mickle, G. R.
The relation between pyrrhotite gangue and the accompanying rocks of the Sudbury district.
Sudbury Jour., 1894.

Münzing, L.
Process for the electrolytic production of nickel.
German Pat. 81888, Aug. 15, 1894.
Abst., Berg- und Hüttenmänn. Ztg., 1896, v. 55, p. 33.
Z. angew. Chemie, 1895, v. VIII, No. 13, pp. 376, 377.
Fischer's Jahresbericht, 1895, v. 41, pp. 196, 197.

Richardson, C. G., Toronto.
Process of refining nickel and copper mattes.
U.S. Pat. 518,117, Apr. 10, 1894.

Ricketts, D. de P.
Process of electrolytic separation of nickel from copper.
U S. Pat. 514,276, Feb. 6, 1894.

Sack, E.
Process for removing iron, manganese and alumina from cobalt and nickel-containing liquors.
German Pat. 72579. (Abst.) Fischer's Jahresbericht, 1894, v. 40, p. 245.
Z. angew. Chemie, 1894, v. VII, p. 170.

Stahl, W.
Chloridizing roasting of low-grade nickel ores.
Berg- und Hüttenmänn. Ztg., 1894, v. 53, pp. 105, 106.
(Abst.) Fischer's Jahresbericht, 1894, v. 40, pp. 248, 249.

Stapff, F. M.
Note on the history of nickel (reply to Austin).
Berg- und Hüttenmänn. Ztg., 1894, v. 53, p. 106.

Styffe, K.
Nickel and its most important alloys.
Jernkontorets Annales, 1894, v. 49, pp. 43-86.
Translated in ''Oesterr. Zeits. Berg- und Hüttenwesen, 1894, v. 42, No. 26, pp. 307-311; No. 27, pp. 324-327; No. 28, pp. 340, 341, 354-357.

Vogt, J. H. L.
Concerning the formation of ore bodies by differentiation in eruptive magmas.
Comptes-Rendus Congrès Geol. Int., 1894, Zurich.

Walker, T. L.
Notes on nickeliferous pyrite from Murray Mine, Sudbury (Ontario).
Amer. Jour. Science, 1894, v. 47 (3rd Series), pp. 312-314.

Wedding, H.
Nickel alloys.
Verh. Vereins z. Beforderung des Gewerbefleisses, 1894, p. 127 et seq.

1895—Browne, D. H.
Segregation in ores and mattes.
School of Mines Quart., 1894, 1895, July, vol. XVI, pp. 297-311.
Appended note by J. F. Kemp, pp. 311, 312.

Frey, H. G.
Formation of nickel carbonyl.
Ber. d. deutsch. Chem. Gesell., 1895, v. 28, pp. 2512-2514.
(Abst.) J. Chem. Soc. (London), 1896, v. 70, II, p. 107.
J. Soc. Chem. Ind., 1896, v. XXV, p. 199.

Charleton, A. G.
** Dressing and metallurgical treatment of nickel ores.
J. Soc. Arts, vol. 43, pp. 609-661, with discussion.

Heibling, J., Grenoble (France).
Improvements in the electrolytic manufacture of ferro-manganese, ferro-chrome, ferro-aluminium, ferro-nickel, and other alloys having an iron base (carbon and lime flux).
British Pat. 18487, Oct. 3, 1895.
(Abst.) J. Soc. Chem. Ind., 1896, v. XV, pp. 726, 727.

Helmhacker, R. (Prague).
Nickel ores in the Ural Mountains
Berg- und Huttenmann. Ztg., 1895, v. 54, p. 142.

Hoffmann, G. Chr.
Report of the section of chemistry and mineralogy.
Canada, Geol Survey, Annual Report, 1895, v. VIII, pp. 27R-29R, 9S, 65S.

Kemp, J. F.
Origin of ore deposits.
School of Mines Quart., 1895, vol. 16, July, pp 311, 312.
Origin of ores.
Min. Ind, 1895, vol. IV, pp 755, 766.

Mond, L., London.
Improvements in apparatus for treating with carbon monoxide nickel ores, and other materials containing nickel.
British Pat. 23665, Dec. 10, 1895.
(Abst.) J. Soc. Chem. Ind, 1897, v. XVI, p. 47.

Mond, L, London.
Apparatus for treating nickel ores or other materials containing nickel with carbon monoxide.
U S Pat. 551220, Dec 10, 1895.

Mond, Ludwig.
** The history of my process of nickel extraction.
Mineral Industry, 1895, vol. IV, pp 743-754.

Schnabel, C.
Recent progress in metallurgy. (Nickel.)
Z. Vereins deutsche Ing., 1895, v. 39, No. 44, pp. 1321-1326.
Chem. Ztg, 1896, v. 20, pp. 595-599.
(Abst.) J. Soc. Chem. Ind., 1896, v. XV, p. 654.

Vogt, J. H L.
The formation of eruptive ore deposits.
Mineral Industry, 1895, vol. IV, pp. 743-754.

Walker, T. L.
Diabase dykes in the Sudbury district.
Trans. Ontario Mining Inst., 1895.

Wedding.
Production of nickel from Canadian ores.
Official Report of the Chicago Exhibition, 1893.
Berg- und Hüttenmänn. Ztg, 1895, v. 54, pp. 207, 208.

Nickel and cobalt.
Mineral Industry, 1896, v. V, pp. 427-433.

1896—Austin, W. L.
Nickel.
II Paper: The nickel deposits near Riddle's, Oregon.
Colorado Scientific Society, 1896, Jan. 6, v. 5, p. 173-196.

Bell, R.
Geology of French River Sheet, Ontario.
Canada Geol. Survey, 1896, Part I, pp. 6-13, 69.

Browne, D. H.
Segregation in ores and mattes.
Can. Rec. Sci, 1896, pp. 176-190.

Chesneau, G.
Sulphides of cobalt and nickel.
Comptes-Rendus de l'Académie des Sciences, 1896, v. 123, pp. 1068-1071.
(Abst.) J. Chem. Soc. (London), 1897, v. 72 (II), p. 172.

Edwards, H. W.
Bessemerizing nickel matte.
J. Soc. Chem Ind., 1896, v. 15, pp. 96-99.
Engng. & Min. Jour., 1896, May 2, v. 61, p. 422.
Fischer's Jahresbericht, 1896, v. 42, pp. 190-192.

Hoffman, G. Chr.
Report of the section of chemistry and mineralogy.
Canada, Geol. Survey, Annual Report, 1896, v. IX (New Series), pp. 28R-39R, 106S-108S.

Le Verrier, U.
Cours de Métallurgie professé à l'Ecole des Mines de Saint Etienne, 1896.
Paris, Baudry & Cie., pp. 168-175.

Moissan, H., and Ouvrard, L.
Le Nickel.
Paris, Gauthier-Villars et Fils, 1896.

Mond, L., London.
Apparatus for treating nickel ores.
Canadian Pat. 52,789, July 2, 1896 (6 years).
Can. Patent Office Record, 1896, v. 24, p. 677.

Phillips and Louis.
A Treatise on Ore Deposits, 1896, Second Edition, p. 180.

Quincke, F.
Letter to the editor, in reply to L. Mond's article "on the history of my nickel extraction process," published in the Jour. Soc. Chem. Ind. Chem. Ztg., 1896, v. 20, No. 1, p. 9.

Storer, T., Glasgow.
Improvements in the treatment of nickel ores for extraction of the nickel, and the production of iron oxide pigment.
British Pat. 22721, Oct. 13, 1896.
(Abst.) J. Soc. Chem. Ind., 1897, v. XVI, p. 919.
German Pat. 100142 (1898). (Abst.) Fischer's Jahresbericht, 1898, v. 44, p. 169.

Ulke, T.
Modern American nickel refining.
Z. Elektrochem, 1896-1897, v. III, No. 23, pp. 521-524.
Abst., J. Soc. Chem. Ind, 1897, v. 16, p. 740
Fischer's Jahresbericht, 1896, v. 42, pp. 185-190.

1897—Nickel and cobalt.
Mineral Industry (edited by R. P. Rothwell), 1897, vol. VI, pp. 494-501.
Nickel mining in the Sudbury district, by A. McCharles, pp. 501-503.
The nickel market in Europe, by D. Levat, p. 503. Progress in the electrolytic refining of nickel in 1897, by T. Ulke, pp. 504-506.

Anonymous.
A new process for the extraction of nickel.
Engng. & Min. Jour., 1897, v. 64, p. 696.
Berg- und Hüttenmänn, Ztg., 1898, v. 57, p 131.

Anonymous.
Electrolytic nickel.
Berg- und Hüttenmänn. Ztg., 1897, v. 56, p. 74.
Dingler's Polytechn Jour., 1897, v. 306, p. 264.

Anonymous.
A new process for separating nickel and copper.
Engng. Min. Jour., 1897, v. 63, No. 14, p. 328.
(A short résumé of Hybinette's U.S. Pat. 579111.)

Bailey, L. W.
The mineral resources of the Province of New Brunswick.
Canada, Geol. Survey, Annual Report, 1897, v. X (New Series), pp. 27-30M, 141-145S.

Bonney, T. G.
Origin of Sudbury ores.
Quart. Jour. Geol. Soc., London, 1897, vol. 53, p. 66.

Garnier, J.
The fluidity of melted nickel.
Comptes-Rendus de l'Académie des Sciences, 1897, v. 124, pp. 1447, 1448.
(Abst.) J. Chem. Soc. (London), 1897, v. 72, II, p. 496.

Hybinette, N. V., Brooklyn, Assignor to A. R. Ledoux, New York.
Process of separating nickel from copper in ore or matte.
U.S. Pat. 579111, Mar. 16, 1897.
(Abst.) Engng. Min. Jour., 1897, v. 63, p. 428.

Mourlot, A.
Effect of a high temperature on copper, bismuth, silver, tin, *nickel*, and cobalt sulphides.
Comptes-Rendus de l'Académie des Sciences, 1897, v. 124, pp. 768-771.
(Abst.) J. Chem. Soc. (London), 1897, v. 72, II, pp. 372, 373.

Nernst, W., and Borchers, W.
Review of the metallurgy of nickel, with particular reference to the electrolytic refining of nickel.
Jahrbuch d. Elektrochemie, 1897, v. IV, pp. 300-308.

Neumann, B.
The electrolysis of copper-nickel alloys.
Berg- und Hüttenmänn. Ztg., 1897, v. 56, No. 35, pp. 287-290, 334-337.
(Fig. 1-4, plate VI and 1 table.)

Thompson, R. M
Process for the extraction of nickel.
German Pat. 91,288. Abst., Fischer's Jahresbericht, 1897, v. 43, p. 263.
Z, angew. Chemie, 1897, v. X, pp. 376, 377.

Ulke, T.
Separation of nickel and copper in matte, and the recovery of the contained precious metals.
Engng. & Min. Jour., 1897, v. 63, pp 113, 114.
Abst., J. Soc. Chem. Ind, 1897, v. 16, p. 262.
Berg- und Hüttenmänn. Ztg., 1897, v. 56, pp. 275, 276.

Ulke, T.
Progress of electro metallurgy in the United States.
II. Modern nickel refining.
Zeit. für Elektrochemie, 1897, v. 3, pp. 521-524.
Abst., J. Soc. Chem. Ind., 1897, vol. XVI, pp. 740, 741.

Vogt, J. H. L.
Can Norwegian nickel plants compete with Canadian plants?
(A pamphlet, published in Christiania under the title "Kan norske nikkelwerk konkurrere med de canadiske?" 1897.)
Abst., Berg- und Hüttenmänn. Ztg., 1897, v. 56, pp. 303, 304.

Walker, T. L.
Geological and petrographical studies of the Sudbury nickel district (Canada).
Quart. Jour. Geol. Soc., London, 1897, v. 53, pp. 40-65.
(Bibliography appended.)

Nickel and cobalt.
Mineral Industry (edited by R. P. Rothwell), 1898, vol. VII, pp. 522-530.

Cowper Coles, Sherard.
Some notes on the recovery and refining of nickel.
Elec. Rev. (Lond.), 1898, v. 43, pp. 926, 927.

Donath, Ed., and Pollak, K.
The production of nickel from oxidized ores by the Mond process.
Berg- und Huttenmänn. Ztg., 1898, v. 57, pp. 368, 369.
(Fig. 12-15, plate IV.)

Foerster, Prof. F.
On the electrolytic deposition of nickel from the aqueous solutions of its sulphate or chloride.
I. Electrolysis of nickel chloride solutions with carbon anodes.
Z. Elektrochemie, 1897, vol. IV, pp. 160-165.
Abst., Berg- und Hüttenmänn. Ztg., 1898, v. 57, p. 27.
J. Chem. Soc. (London), 1898, vol. 74, II, pp. 227, 228.

1898—Grosse-Bohle, H.
Process for obtaining cobalt and nickel.
German Pat. 97114. (Abst.) Fischer's Jahresbericht, 1898, v. 44, pp. 169, 170.
Z. angew. Chemie, 1898, v. XI, p. 363.

Miller, Willet G.
On some nickeliferous magnetites.
Brit. Asso. Adv. Sci., 1898, pp. 660, 661, Report 1897.

Mond, L., London.
Improvements in apparatus for the treatment of nickel ores and other nickel-bearing substances by means of carbon monoxide.
German Pat. 95417, Class 40. Abst. Berg- und Hüttenm. Ztg., 1898, v. 57, p. 266.
Z. angew. Chemie, 1898, vol. XI, No. 2, pp. 41-43.
Fischer's Jahresbericht, 1898, v. 44, pp. 170-172.

Mond, L., London.
A process for obtaining metallic nickel from nickel carbonyl.
British Pat. 1106, Jan. 14, 1898.
(Abst.) J. Soc. Chem. Ind., 1899, vol. 18, p. 49.

Roberts-Austen, W. C.
** Extraction of nickel from its ores by the Mond process.
Proc. Inst. Civil Engrs., Nov. 8, 1898, v. 135, pp. 29-53.
Chem. News, 1898, v. 78, No. 2035, pp. 260, 261.
Engng. Min. Jour., 1898, Dec. 31, v. 66, p. 784.
J. Soc. Chem. Ind., 1899, v. 18, pp. 764-767.

Ulke, T.
The mining, smelting and refining of nickel.
Engng. Mag., 1898, vol. XVI, pp. 215-226, 451-456.

1899—Nickel and cobalt.
Mineral Industry (edited by R. P. Rothwell), 1899, v. VIII, pp. 431-437.

King, Clarence.
On the Rossland, B.C., Ore Bodies, Evidence, Records of the Supreme Court of British Columbia, 1899; Suit of Iron Mask versus Centre Star.

Lindgren, W.
On the Rossland, B.C., Ore Bodies, Iron Mask versus Centre Star, 1899.

McCharles, A.
The Sudbury nickel mines in Ontario.
Engng. Min. Jour., 1899, v. 67, pp. 144, 145.

Power, Fr. D.
The mineral resources of New Caledonia.
Trans. Inst. Mining & Metallurgy, 1899, 1900, vol. VIII, pp. 427-465.

Nickel and cobalt.
Mineral Industry, 1900, vol. IX, pp. 474-481.

Anonymous.
Canadian nickel.
Berg- und Huttenmänn. Ztg., 1900, v. 59, p. 267.

1900—Anonymous.
Nickel mining in Ontario.
U.S. Consular Reports, 1900, Feb., No. 235.
(Abst.) J. Soc. Chem. Ind., 1900, vol. 19, p. 286.

Anonymous.
Nickel mining in New Caledonia.
Engng. & Mng. Jour., 1900, June 23, v. 69, pp. 735, 736.
Abst., J. Soc. Chem. Ind., 1908, p. 748.

Bain, J. W.
A sketch of the nickel industry.
Ontario, Report of the Bureau of Mines, 1900, vol. IX, pp. 213-223.
A letter from the president of the Orford Copper Co. (R. M. Thompson) to the Bureau supplies interesting details dealing with the historical development of the Orford process.

Coehn, A., and Solomon, E.
Method for the electrolytic separation of nickel from cobalt.
German Pat. 110615, 1900.
(Abst.) Fischer's Jahresbericht, 1900, v. 46, p. 157.

Compagnie Electro-métallurgique des Procédés Gin et Leleux, Paris.
Treatment of nickel, cobalt or copper ores in the electric furnace.
German Pat. 108946, 1900.
(Abst.) Fischer's Jahresbericht, 1900, vol. 46, pp. 157, 158.

Donath, Ed., and Margosches, B. M.
Recent progress in the metallurgy of nickel.
Oesterr. Zeits. f. Berg- und Hüttenwesen, 1900, vol. 48, pp. 245-248, 260-263, 277-279.

Frasch, H. A., Hamilton (Canada).
Process for the electrolytic recovery of metals from ores.
German Pat. 131415, Class 4a, Dec. 18, 1900.
Abst., Berg- und Hüttenmänn. Ztg., 1902, v. 61, p 496.
Z. angew. Chemie, 1902, v. 15, No. 25, p. 632.

Herrenschmidt, H. L., Paris.
Production of nickel from nickel ores low in sulphur.
German Pat. 143391, Dec 30, 1900.
(Abst.) Fischer's Jahresbericht, 1903, vol. 49, p. 166.
Zeits. f. angew. Chemie, 1903, vol. XVI, p. 756.

Kugel, M. (Berlin).
Electrolytic deposition of nickel or its allied metals, or alloys of these metals (production of tough, rollable nickel).
British Pat. 2994, 1900, Feb. 14, German Pat., 117054, 1900.
(Abst) Fischer's Jahresbericht, 1900, vol. 46, pp. 154, 155.
J. Soc. Chem. Ind., 1901, v. 20, p. 260.

Le Verrier, U.
Electrolysis (of nickel) and electrolytic apparatus.
British Pat. 5781, Mar. 16, 1900. German Pat. 112890, 1900.
Abst., J. Soc. Chem. Ind., 1900, vol. XIX, p. 254.
Fischer's Jahresbericht, 1900, v. 46, pp. 156, 157.

Lindgren, W.
Metasomatic processes in fissure veins.
Trans. Am. Inst. Min. Eng., 1900, vol. XXX, p. 578.

Mond, L.
The Mond nickel extraction process.
Revue générale de chimie pure et appliquée, vol. II, No. 4.
Berg- und Huttenmann. Ztg., 1900, v. 59, pp. 346-348 (plate VI).

Struthers, J.
The Hans A. Frasch electrolytic process for extracting metals, as applied to copper-nickel matte.
Engng. & Min. Jour., 1900, Sept. 8, vol. 70, pp. 272, 273.

1901—Nickel and cobalt.
Mineral Industry for 1901, vol. X, pp. 484-491, 492-500.
Progress in the metallurgy of nickel during 1901, by T. Ulke.

Anonymous.
The Frasch electrolytic process for refining nickel and copper.
(U.S. Pats. 669439-669442 of Mar. 5, 1901, and U.S. Pat. 669899 of Mar. 12, 1901.)
Engng. & Min. Jour., 1901, Apr. 6, vol. 71, pp. 428, 429.
(Abst.) J. Soc. Chem. Ind., 1901, vol. XX, p. 483.

Barlow, A. E.
The Sudbury district.
Canada Geol. Sur., Summary Report, 1901, vol. 14, pp. 143A-147A.

Beck, R.
Lehreyon den Erzlagerstätten, 1901, p. 43.

Boudouard, O.
Researches on chemical equilibria. (Reduction of nickel oxide.)
Annales de Chimie et de Physique, v. 24 (7th Series), 1901, pp. 74-85.

Frasch, H. A., Hamilton (Can.).
Process for producing a nickel ammonium compound.
British Pat. 19035, Sept. 24, 1901.
(Abst.) J. Soc. Chem. Ind, 1902, v. 21, p. 253.
Same as German Pat. No. 146363, Jan. 9, 1901.
(Abst) Fischer's Jahresbericht, 1903, v. 49, pp. 166, 167.
Z. angew. Chemie, 1903, vol. XVI, p. 1110.

Kemp, J. F.
The deposits of copper ores at Ducktown, Tenn.
Trans. Am. Inst. Min. Eng., 1901, vol. XXXI, p. 244.

Kershaw, J. B. C.
The electrochemical and electrometallurgical industries of the world in 1900. (Electrolytic nickel.)
Electrician, 1901, v. 46, p. 428.

Le Roy.
Electrolytic method of extraction of cobalt and nickel.
Bull. Soc. Industrielle de Mulhouse, Procès-Verbaux, 1901, v. 71, pp. 154, 155.

Perron, C.
Process for leaching low-grade pyritic nickel-ores.
German Pat. 137006, Class 40a, Nov. 29, 1901.
Abst., Z. angew. Chemie, 1902, v. 15, No. 49, p. 1276.
Fischer's Jahresbericht, 1903, v. 49 (Unorgan. Teil), p. 165.

Siemens & Halske Akt.—Gesell.
Process for the dry sulphatization of ores containing magnesium, nickel, copper and iron in the form of oxidic, silicate or carbonate compounds.
German Pat. 130298, Mar. 2, 1901.
Fischer's Jahresbericht, 1902, v. 48, pp. 190-192.
Z. angew. Chem., 1902, vol. XV, p. 340. J. Soc. Chem. Ind, 1902, v. XXI, p 617.
Same as British Pat. 16337, Aug. 14, 1901.

Vogt, J. H. L.
Problems in the geology of ore deposits
Trans. Am. Inst. Min. Eng, 1901, vol. XXXI, p. 125.

Thofern, H. G. C., and De Sainte Seine, B.
Process for extracting nickel and copper from their ores.
British Pat. 10101, May 15, 1901.
(Abst.) J. Soc. Chem. Ind., 1902, vol. XXI, p. 862.

1902—Allgemeine Elektro-Metallurgische Gesellschaft m.b.H.
Process for the chlorination of metal-sulphur compounds in the wet way.
German Pat. 150445, Aug. 8, 1902 (Class 40a).
(Abst.) Fischer's Jahresbericht, 1904, vol. 50, (Unorg. Teil), pp. 208, 209.
Zeits. f. angew. Chemie, 1904, vol. XVII, p. 693.

Bergmann, F. J., Neheim a-Ruhr (Germany).
Process for the production of nickel from nickel ores.
German Pat. 140232, May 1, 1902.
(Abst.) Fischer's Jahresbericht, 1903, v. 49 (Unorg. Teil), pp. 165, 166.
Zeits. f. angew. Chemie, 1903, vol. XVI, p. 287.

Barlow, A. E.
The Sudbury mining district.
Canada, Geo. Survey, Summary Report, 1902, pp. 254-269.

Browne, D. H., Assignor to the Canadian Copper Co., Cleveland.
Process of electrolytic separation of copper and nickel.
U.S. Pat. 714861, Dec. 2, 1902.
Abst., Engng. Min. Jour., 1902, Dec. 20, v. 74, p. 823.
J. Soc. Chem. Ind., 1903, v. 22, p. 35.

Vogt, J. H. L.
Platingehalt in Norwegischen nickelerz.
Zeit. fur prakt. Geol., Aug., 1902.

Dickson, C. W.
Note on the condition of nickel in nickeliferous pyrrhotite from Sudbury.
Engng. Min. Jour, 1902, vol. 73, No. 19, p. 660.

Dürre, E. F.
Remarks on the modern metallurgy of nickel and its development, with particular reference to the modern point of view and experience.
Chemische Zeitschrift (Leipzig), 1902, Nov.-Dec., p. 137.

Guillet, Léon.
The Mond process for the extraction of nickel.
Genie Civil, 1902, v. 41, pp. 72-74.

Haas, H. L.
Process of melting nickel.
U.S. Pat. 709218, Sept. 16, 1902.

Hoepfner, C, Frankfort-on-the-Main (Germany).
Process of extracting copper and nickel from sulphide compounds.
U.S. Pat. 704640, July 15, 1902. (Abst.) J. Soc. Chem. Ind., 1902, v. 21, p. 1081.

Illner.
The nickel-ore deposits of Frankenstein (Silesia) and the mining and smelting operations based thereon.
Zeitschr. für. Berg- Hütten- u. Salinenwesen im Preuss. Staate, 1902, vol. 50, pp. 816-823.

Mittasch, A.
On the chemical dynamics of nickel carbonyl. ($Ni(CO)_4$.)
Z. physik. Chemie, 1902, vol. 40, pp. 1-83.
Abst., J. Chem. Soc. (London), 1902, vol. 82, II, pp. 307, 308.

Perron, C. (Rome).
Treatment of nickel and copper-nickel ores.
U.S. Pat. 709277, Sept. 16, 1902.
(Abst.) J. Soc. Chem. Ind., 1902, vol. XXI, p. 1281.

Roberts-Austen, Sir W. C.
An introduction to the study of metallurgy.
London, 1902, fifth edition, pp. 400-418.
Wet process for treating nickel and cobalt ores. The extraction of nickel from its ores by the Mond process.

Shuler, D. P., Sudbury (Canada).
Process of treating copper-nickel sulphide ores.
U.S. Pat. 697370, Apr. 8, 1902.

Siemens u. Halske Akt.-Gesell.
Process for the manufacture of a nickel oxide adapted for reduction in an electric furnace, and for the purification of other metallic hydrates.
German Pat. 151964, June 18, 1902 (Class 40a).
(Abst.) Fischer's Jahresbericht, 1904 v. 50, pp. 206, 207.
Z. angew. Chemie, 1904, v. 17, II, p. 1618.
Abst., Metallurgie, 1904, vol. I, p. 229.

Silver, L. P.
The sulphide ore bodies of the Sudbury region.
Jour. Canadian Min. Inst., 1902, vol. V, pp. 528-551.
(Short and incomplete bibliography appended.)

Struthers, J., and Newland, D. H.
Nickel and cobalt.
Mineral Industry for 1902, vol. XI, pp. 484-494.
Progress in the metallurgy of nickel during 1902, pp. 490-494, by T. Ulke.

Thofern and St. Seine.
Metallurgical refining process (applied to nickel matte).
Oesterr. Zeits. f. Berg- und Hüttenwesen, 1902, vol. 50, No. 44, p. 585.

Nickel and cobalt.
Mineral Industry for 1903, vol. XII, pp. 276-280.

1903—Beck, R., Freiberg.
The nickel-ore deposit of Schland a.d. Spr. (Saxony, Germany) and the minerals.
Reprint from the "Zeits. d. Deutsch. Geol. Ges.," 1903, pp. 296-331.

Borchers, W.
Elektrometallurgie des Nickels.
Vol. VI of the "Monographien uber angewandte Elektrochemie," published by V. Engelhardt.
1903, Druck und Verlag von W. Knapp, Halle a.S., 35 pp. (pamphlet).

Borchers, W.
Elektrometallurgie.
Die Gewinnung der Metalle unter Vermittlung des elektrischen Stromes.
Leipzig, Verlag von S. Hirzel, 1903, pp. 268-298.
(A complete historical account of the electrolytic deposition of nickel, with numerous foot-note references.)
English translation of this text-book published in London, 1904.
(Ch. Charles Griffin & Co.) under the title: Electric smelting and refining, pp. 273-300.

Coleman, A. P.
The Sudbury nickel deposits.
Ont. Bur. Mines, 1903, vol. 12, pp. 235-303.

Dewar, J., Cambridge.
Manufacture of nickel carbonyl and its treatment for production of metallic nickel therefrom.
British Pat. 9300, Apr. 22, 1902.
(Abst.) J. Soc. Chem. Ind., 1903, vol. XXII, pp. 700, 701.
Same as German Pat. No. 149559, Apr. 16, 1903.
(Abst.) Fischer's Jahresbericht, 1904, vol. 50, pp. 207, 208.
Z. angew. Chemie, 1904, vol. XVII, pp 895, 896.

Glasser, E.
Report on the mineral wealth of New Caledonia submitted to the French Minister of Colonies. (The nickel mines.)
Annales des Mines, 1903, vol. IV (10th Series), pp. 363-391, 397-536.

Gunther, E. F.
Process for the production of copper and nickel from magnetic pyrites containing these metals.
(Dissert. Aachen) Zeits. f. Elektrochemie, 1903, vol. IX, p. 133.

Kemp, J. F.
The ore deposits of the U.S. and Canada.
1903, 5th ed., pp. 61, 65; 428-441.
Numerous foot-references to the most important articles.

Leckie, Major R. G.
Nickel deposits in New Caledonia.
Jour. Canadian Min. Inst., 1903, v. VI, pp. 169-179.

Leith, C. K.
Moose mountain iron range.
Ontario, Report of the Bureau of Mines, 1903, vol. XII, pp. 318-321.

Siemens & Halske Akt.—Ges.
Preparation of a nickel monoxide suitable for reduction in an electric furnace.
French Pat. 337712, Dec. 12, 1903.
(Abst.) J. Soc. Chem. Ind., 1904, vol. XXIII, p. 546.

Siemens & Halske Akt.—Ges., Berlin
Process for the dry sulphating of ores containing the heavy metals, iron, nickel, copper, silver as sulphides and arsenides and the light metals, such as Mg, Al and the alkali metals in the form of either oxidized compounds, silicates or carbonates.
German Pat. 138261, Mar. 2, 1903. (Addition to German Pat. 130298).
(Abst.) Fischer's Jahresbericht, 1903, vol. 49, pp. 173-176.
Z. Angew. Chemie, 1903, vol. XVI, p. 139.

Sjöstedt, E. A.
Development in the nickel industry at Sault Ste. Marie. Ontario (Can.).
Engng. Min. Jour., 1903, Apr. 25, vol. 75, p. 632.

Sjostedt, E. A., and James, J. H., Assignors to F. H. Clergue, all of Sault Ste. Marie (Can.).
Electrolytic separation of copper and nickel from mattes and ores.
U S. Pat. 725998, Apr. 21, 1903.
(Abst.) J. Soc. Chem. Ind., 1903, vol. XXII, p. 637.
Metallurgie, 1904, vol. I, p. 370.
Same as British Pat. 14731, July 2, 1903.

Soc. Elec. Metall. Francaise.
French Pat. 336376, Oct. 30, 1903.
Electric process for the extraction of nickel from garnierite and other minerals.
British Pat. 23380, 1904. (Abst.) J Soc. Chem. Ind., 1904, v. 23, p. 378.

Spurr, J E.
A consideration of igneous rocks and their segregation or differentiation as related to the occurrence of ores
Trans. Amer. Inst. Min. Engrs., 1903, vol. XXXIII, pp. 305, 306.

Ulke, T.
History and present development of electrolytic nickel refining.
Electrochem. Ind., 1903, vol. I, No. 6, pp. 208-212.

1904—Nickel and cobalt.
Mineral Industry for 1904, vol. XIII, pp. 335-343.

Anonymous.
The cost of production of nickel from New Caledonia ores.
Engng. Min. Jour., 1904, vol. 77, p. 727.

Barlow, A. E.
Nickel and copper deposits of Sudbury, Canada, Geol. Sur., 1904, vol. 14, part H, with geological maps. (Reprinted in 1907.)

Coleman, A. P.
Sudbury nickel-bearing eruptive.
Bull. Geol. Soc. Amer., 1904, vol. XV, p 551 (Abst.).
The northern nickel range.
Ontario Report of the Bureau of Mines, 1904, vol. XIII, part I, pp 192-215.
The northern nickel range.
Ontario, Report of the Bureau of Mines, 1904, vol. 13, part I, pp 192-194

Dewar, J., Cambridge.
Manufacture of nickel carbonyl.
U.S. Pat. 760852, May 24, 1904.
(Abst.) J. Soc. Chem. Ind., 1904, vol. XXIII, p. 660.

Dickson, C. W.
The ore deposits of Sudbury, Ontario.
Trans. Amer. Inst. Min. Engrs., 1904, vol XXXIV, pp. 3-67.

Gin, G. H.
Manufacture of nickel or its alloys in the electric furnace.
French Pat. 344202, June 22, 1904. British Pat. 8221, Apr. 18, 1905.
(Abst.) J. Soc. Chem. Ind., 1904, vol. XXIII, p 1098.
Same as German Pat. 175886, Mar. 30, 1905 (class 40c).
(Abst.) Fischer's Jahresbericht, 1906, v. 52 (Unorg. Teil), pp. 219, 220.
Zeits. f. angew. Chemie, 1907, vol. XX, p. 592.

Günther, E.
Experiments on the direct electrolytic treatment of concentrated nickel matte.
Metallurgie, 1904, vol I, pp. 77-81.
Z Elektrochemie, 1904, vol. X, pp. 836, 837.
(Abst.) J. Soc. Chem. Ind., 1904, vol. XXIII, p. 1034.
Fischer's Jahresbericht, 1904, vol. 50 (Unorg. Teil), p. 211.

Hess, J.
Development of the electrolytic production of nickel.
Z Elektrochemie, 1904, vol. X, pp. 821-826.
A very complete review of the literature and patents with numerous foot-note references.

Hixon, H. W.
Geology of the Sudbury district.
Eng. Min. Jour., vol. 78, Dec. 29, 1904, pp. 1022, 1023.

Jones, H. O.
Constitution of nickel carbonyl.
Chem. News, 1904, vol. 90, pp. 144, 145.

Le Blanc, M., and Levi, M. G.
Passivity of nickel.
Boltzmann Festschrift, 1904, pp. 183-195.
(Abst.) Chem. Zentralblatt, 1904, I, pp. 1396, 1397.
J. Soc. Chem. Ind., 1904, vol. XXIII, p. 667.

Moffett, R. R., Bayonne, N.J., Assignor to International Nickel Co., N.J.
Furnace for reducing and smelting nickel oxides.
U.S. Pat. 774591, Nov. 8, 1904.
(Abst.) J. Soc. Chem. Ind., 1904, vol. XXIII, p. 1151.

Malzac.
Treatment of silicate nickel ores.
British Pat. 1556, Jan. 21, 1904.

Miller, Willet G.
Cobalt-nickel arsenides and silver.
Ontario, Report of the Bureau of Mines, 1904, vol 13, pt. I, pp. 96-103.

Neumann, B.
Die Metalle. Geschichte, Vorkommen und Gewinnung, mebst ausführlicher. Produktions und Preis-Statistik. (Book.)
1904, Halle a-S. Verlag von W. Knapp, pp. 326-345.
An interesting account of the history of nickel serves as introduction to this chapter.

Ohly.
The metallurgy of nickel and cobalt.
Mng. Repoiter, 1904, vol. 50, pp. 105-108.

Société Electro-Métallurgique Francaise, Froges (Isère, France).
Process for the production of nickel in the melted condition, entirely free from sulphur, and low in carbon and silicon.
German Pat. 182735, Oct. 30, 1904.
(Abst.) Fischer's Jahresbericht, 1907, v. 53 (Unorg. Teil), pp. 233, 234.
Z. angew. Chemie, 1907, vol. XX, p. 2142.

Stelzner, A. W., and Bergeat, A.
Die Erzlagerstätten.
1904, vol. I, pp. 42-63; vol. II, pp. 576-585.

Vogel, O.
The nickel plant of the Aktiebolaget Evje.
Metallurgie, 1904, vol. I, pp. 242-245.

Beck and Weed.
The Nature of Ore Deposits, 1905, p. 32.

1905—Aiken, R. H., Winthrop Harbour, Ill.
Process of separating nickel from mattes.
U.S. Pat. 800130, Sept 26, 1905.

Barlow, A. E.
On the origin and relations of the nickel and copper deposits of Sudbury, Ontario (Can.)
Economic Geology, 1905-1906, vol. I, pp. 454-466, 545-553.
The nickel industry.
Min. Jour. (London), 1905, Feb. 25, vol. 77, p. 207.
Metallurgie, 1905, vol. II, pp. 220-222.

Bernard, J.
Separation of nickel and cobalt.
French Pat. 354941, June 5, 1905.
(Abst.) J. Soc. Chem. Ind., 1905, v. XXIV, p. 1177.

Browne, D. H.
Notes on the origin of the Sudbury ores.
Economic Geol., 1905-1906, vol. I, pp. 467-475.

Coleman, A. P.
Geology of the Sudbury district.
Engng. Min. Jour., 1905, vol. 79, pp. 189, 190. (Reply to H. W. Hixon.)
The Sudbury nickel field.
Report of the Ontario Bureau of Mines, 1905, vol. XIV, pt. III, pp. 1-188.

Copaux, H.
Physical characters of pure cobalt and nickel.
Comptes-Rendus de l'Académie des Sciences, 1905, vol. 140, pp. 657-659.

Dickson, C. W.
The distribution of platinum metals in other sources than placers.
Jour. Can. Min. Inst., 1905, vol. VIII, pp. 192-214.

Elworthy, H. S., and Williamson, E. H.
Production of nickel.
British Pat. 7714, Apr. 11, 1905.
French Pat. No. 361452, May 9, 1905. (Abst.) J. Soc. Chem. Ind., 1906, v. XXV, p. 257.

Frasch, H. A.
Extraction of nickel from matte or other nickel-bearing substances.
U.S. Pat. 791090, May 30, 1905.

Gin, G. H.
Manufacture of nickel or its alloys.
First addition, dated Sept. 26, 1905, to French Pat. 344202, June 22, 1904.
(Abst.) J. Soc. Chem. Ind., 1906, vol. XXV, p. 272.

Gin, G.
Process for the electrometallurgic production of carbon-free metals and metal alloys by the action of silicides upon the oxides or basic silicates of the metals to be prepared or to be alloyed resp.
German Pat. 21147, Mar. 29, 1905.

Hanes, G. S.
Solubility of cobalt-nickel ores in ammonia.
J. Canadian Min. Inst., 1905, vol. VIII, pp.. 358-362.

Hixon, H. W.
Geology of the Sudbury district.
Eng. and Min. Jour., Feb. 16, 1905, pp. 334, 335.
Geology of the Sudbury district.
Ibid, Feb. 23, 1905, p. 383.

Hybinette, N. V., Westfield.
Process for separating metals.
British Pat. 25122, Dec. 4, 1905. U.S. Pat. 805969, Nov. 28, 1905.
(Abst.) J. Soc. Chem. Ind., 1906, vol. XXV, p. 29.

Hybinette, N. V., Westfield.
Process for refining copper-nickel matte.
British Pat. 24486, Nov. 27, 1905. U.S. Pat. 805555, Nov. 28, 1905.
French Pat. 359660, Nov. 21, 1905.
(Abst.) J. Soc. Chem. Ind., 1906, vol. XXV, p. 26.

Hybinette, N. V., Westfield.
Process for separately obtaining copper and nickel by roasting and leaching copper-nickel matte or the like.
German Pat. 200372, Nov. 28, 1905.
(Abst.) Fischer's Jahresbericht, 1908, vol. 54, I, p. 273.
Z. angew. Chemie, 1908, vol. XXI, p. 1998.

Imbert, A. H.
Metallurgical process for nickel.
French Pat. 361887, Nov. 4, 1905.
(Abst.) J. Soc. Chem. Ind., 1907, vol. 26, p. 99.

Jamieson, G. S.
On the natural nickel-iron alloy, awaruite.
Amer. Jour. of Science, 1905, vol. XIX (4th Series), pp. 413-415.

Judson, J. N. South Stafford.
Method of separating pyrrhotite from chalcopyrite and gangue.
U.S. Pat. 801879, Oct. 17, 1905.

Krull, F.
Production and market position of copper, lead, zinc, tin, nickel and aluminium.
Zeit. f. angew. Chemie, 1905, vol. XVIII, pp 84-92.—The world's production rose from 1,829 tons in 1889 to 9,850 tons in 1903, about one-half being obtained from New Caledonia minerals and the balance mainly from the United States and Canada. The price has varied as follows: 1889, 4 5 marks per kilo; 1901, 2.9-3.2 marks; 1902, 2.9-3.5 marks; 1903, 3-3.75 marks.

Lance, D.
Process of obtaining the hydroxides of Cu, Zn, Cd, Ag, nickel, cobalt, and tungsten in the wet way, by direct extraction
Second addition, dated Jan. 9, 1905, to French Pat, 342865, May 3, 1904.
(Abst.) J. Soc. Chem. Ind, 1905, vol. XXIV, p 845

Langer, C., Glamorgan (South Wales), Assignor to the Mond Nickel Co, Ltd.
Apparatus for obtaining nickel from nickel carbonyl.
British Pat. 13350, June 28, 1905
(Abst.) J. Soc. Chem. Ind., vol. XXIV, p. 1070.
Same as U.S Pat. 825844, July 10, 1906, and German Pat. 177964, June 29, 1905.
(Abst) Fischer's Jahresbericht, 1906, vol. 52, pp. 220, 221.
Same as U S Pat. 825844, July 10, 1906.

Langer, C., Glamorgan, Assignor to the Mond Nickel Co.
Treating nickel ores, or other material containing nickel, with carbonic oxide, and apparatus therefor.
British Pat. 13351, June 28, 1905. U.S. Pat. 815717, Mar. 20, 1906.
(Abst.) J. Soc. Chem. Ind., 1905, vol. XXIV, p. 1113.
Same as German Pat. 177965, June 29, 1905.
(Abst.) Fischer's Jahresbericht, 1906, vol. 52, pp. 221, 222.
Z. angew. Chemie, 1907, vol. XX, p. 590.
Same as U.S. Pat. 815717, Mar. 20, 1906.

MacIvor, R. W. E., and Fradd, M, London (Metals Extraction Corporation, Ltd.).
Treatment of ores containing nickel.
British Pat. 6255, Mar 24, 1905. French Pat. 362676, Jan. 25, 1906.
(Abst.) J. Soc. Chem. Ind., 1906, vol. XXV, p. 541.
Same as U.S. Pat. 859776, July 9, 1907.

MacIvor, R. W. E., and Fradd, M., London (Metals Extraction Corporation, Ltd.).
Treating nickel ores or oxidized nickel mattes.
British Pat. 10869, May 24, 1905.
(Abst.) J. Soc Chem. Ind., 1906, vol. XXV, p. 588.
Same as U.S. Pat. 846496, Mar. 12, 1907.
French Pat. 362675, Jan. 25, 1906.

Moffett, R R., Bayonne (N.J.), Assignor to the International Nickel Co., N.Y.
Method of treating "copper tops" in the refining of nickel-copper matte.
U.S. Pat. 802148, Oct. 17, 1905.

Miller, Willet G.
The cobalt-nickel arsenides and silver deposits of Temiskaming.
Ontario, Report of the Bureau of Mines, 1905, pt. II (2nd ed), 90 pp.

Mond Nickel Co., Ltd.
Process for the treatment of nickel ores and other nickel-bearing substances with carbon monoxide.
German Pat. 27752, June 28, 1905.

The Mond Nickel Co., Ltd.
Process for separating nickel from nickel carbonyl.
German Pat. 27753, June 28, 1905.

Monell, A., New York.
Method of separating nickel and copper sulphides.
U.S. Pat. 802012, Oct. 17, 1905.

Rutherford, F. M.
Chlorinating treatment of nickel ores.
J. Canadian Min. Inst., 1905, vol. VIII, pp. 336-342.

Savelsberg, J., Papenburg a. Ems.
Process for the conversion of oxidic ores or the like into sulphides, applicable particularly to nickel and cobalt ores, with the aid of sulphur or sulphur-containing additions, carbon and fluxes.
German Pat. 172128, Jan. 21, 1905 (Class 40a. Gr.I).
(Abst.) Fischer's Jahresbericht, 1906, vol. 52 (Unorg. Teil), pp. 222, 223.
Zeits. f. angew. Chemie, 1907, vol. XX, p. 158.

Steinhart, O. J.
Metals and their ferro alloys in the manufacture of alloy steels.
Trans. Inst. Min. & Met., 1905-1906, vol. 15, pp. 228-238.

1906—Anonymous.
Production of nickel.
Jour. Chamber of Commerce, 1906, Aug. (Trade Report).
J. Soc. Chem. Ind., 1906, vol. XXV, pp. 814, 815.

Adams, Frank D.
The ore deposits of the Sudbury district, discussion of.
Jour. Can. Min. Inst., 1906, vol. IX, p. 234.

Barlow, A. E.
The ore deposits of the Sudbury district.
Jour. Can. Min. Inst, 1906, vol. IX, pp. 231, 232.

Campbell, W., and Knight, C. W.
Microscopic examination of nickeliferous pyrrhotites
Engng. Min. Jour., 1906, Nov. 17, vol. 82, pp. 909-912.

Coleman, A. P.
Abstract: Magmatic segregation of sulphide ores.
British Ass. Adv. Sci, 1906, Rept. 75th Meeting.

Dickson, C. W.
Genetic relations of nickel-copper ores, with special reference to the deposits at St. Stephen, N.B., and Sohland, Germany.
Jour. Canadian Min. Inst., 1906, vol. IX, pp. 236-260.

Glidden, J. T.
Nickel and cobalt.
Mineral Industry for 1906, vol. XV, pp. 588-597.

Günther, E., and Franke, R.
Process of treating metallic (copper-nickel) ores or mattes.
German Pat. 200953, May 3, 1906 (Class 40 c)
(Abst.) Zeits. f. angew. Chemie, 1908, vol. XXI, p. 1997.
Fischer's Jahresbericht. Chem. Technologie, 1908, vol. 54, I, pp. 272, 273.
Same as U.S. Pat. 879633, Feb. 18, 1908.
(Abst.) J. Soc. Chem. Ind., 1908, vol. 27, p. 289.

Hesse, R.
Experiments on the conversion of nickel matte into nickel by means of an oxygen-enriched blast.
Metallurgie, 1906, vol. III, No. 9, pp. 287-292, 375-381
Electrochem. Met. Ind., 1906, Aug, vol. IV, pp. 330, 331.

Hixon, H. W.
The ore deposits and geology of the Sudbury district.
Jour. Canadian Min. Inst., 1906, vol. IX, pp. 223-235.

Hixon, H. W.
The Sudbury nickel region.
Eng. Min. Jour., 1906, pp. 313, 314.

Hixon, H. W.
Matte converting.
Engng. Min. Jour., 1906, vol. 82, pp. 197, 198.
(Abst.) Metallurgie, 1907, vol. IV, pp. 1-5.

Johnson, W. M., Iola (Kansas).
Method of treating nickel-copper matte.
U.S. Pat. 825056, July 3, 1906. (Abst) Metallurgie, 1907, vol. IV, p. 26.
Electrochem. Met. Ind., 1906, vol. IV, p. 321.

Jongh, A. C., de.
Lime roasting of nickeliferous matte.
Engng. Min. Jour., 1906, Apr. 28, vol. 81, p. 793.

Lehmer, C.
Electric smelting of sulphidic (pyritic) ores and metallurgical products for the direct recovery of metals.—Production of nickel from nickel matte.
Metallurgie, 1906, vol. III, No. 16, pp. 549-555; No. 17, pp. 596-602.

Moffett, R. R., Bayonne (N.J.), Assignor to International Nickel Co.
Separation of nickel from cobalt.
U S. Pat. 838125, Dec. 11, 1906.
(Abst.) J. Soc. Chem. Ind., 1907, vol. 26, p. 156.

Metals Extraction Corporation, Ltd.
Process for obtaining nickel from nickel ores or roasted mattes.
German Pat. 187415, Feb. 8, 1906.
(Abst.) Fischer's Jahresbericht, 1907, vol. 53 (Unorg. Teil), p. 233.
Z. angew. Chemie, 1907, vol. XX, p. 2142.

Metals Extraction Corporation, Ltd.
Process for the extraction and recovery of cobalt and nickel from ores and oxidized mattes.
French Pat. 367717, July 4, 1906.
Abst., J. Soc. Chem. Ind., 1906, vol. XXV, p. 1155.

Moissan, H.
Boiling and distillation of nickel, iron, manganese, chromium, molybdenum, tungsten, and uranium.
Compt.-Rendus de l'Académie des Sciences, 1906, vol. 142, pp. 425-430.

Muscovici, Ar.
Notes on a deposit of nickeliferous pyrrhotite at Malachite Point.
J. Canadian Min. Inst., 1906, vol. IX, pp. 221, 222.

Pratt, J. H.
The production of steel-hardening metals in 1905.
U.S. Geological Survey.
Abst., Metallurgie, 1906, vol. III, pp. 833, 834.

Seigle, A., Lyons (France).
Wet method of extraction of gold, platinum, silver, *nickel* and copper.
French Pat. 363039, Feb. 6, 1906. British Pat. 3575, Feb. 13, 1906.
(Abst.) J. Soc. Chem. Ind, 1906, vol. 25, p. 816.

Thompson, Ph.
The Sudbury nickel region.
Engng. Min. Jour., 1906, vol. 82, pp. 3, 4.

1907—Bleeck, A. W. G.
Origin of the nickel ore deposits of the Black Forest.
Engng. Min. Jour., 1907, vol. 83, p. 418.

Borchers, W., and Warlimont, F.
Treatment of nickel sulphide ores or metallurgical products, containing iron and copper.
German Pat. 200467, May 18, 1907.
(Abst.) J. Soc. Chem. Ind., 1908, vol. XXVII, p. 985.
Fischer's Jahresbericht, 1908, vol. 54, I, pp. 269, 270.

Campbell, W., and Knight, C. W.
On the microstructure of nickeliferous pyrrhotites.
Econ. Geol., 1907, vol. II, pp. 350-366.

Campbell, W., and Knight, C. W.
The microstructure of nickeliferous pyrrhotites, with special reference to the deposits of Sudbury, Ontario, St. Stephen, N.B., and Sohland, Germany.
Jour. Can. Min. Inst., 1907, vol. X, pp. 274-280.

Coleman, A. P.
The Sudbury nickel ores.
Zeit. f. prakt. Geol., 1907, vol. XV, p. 221.

Coleman, A. P.
The need of field work in the study of ore genesis.
Engng. Min. Jour., 1907, vol. 83, pp. 295, 296.

Coleman, A. P.
The Sudbury laccolithic sheet.
Jour. Geol., 1907, vol. XV, pp. 759-782.

Colvocoresses, G. M.
New Caledonia and its minerals.
(Geography, geology and mineral resources of a remote, but interesting island in the Pacific. Discovery, exploration and settlement.)
Engng. Min. Jour., 1907, vol. 84, pp. 532-535.

Diehl, C. A., and Koehler, W., Cleveland (Ohio).
Method of treating nickel ores.
U.S. Pat. 842139, Jan. 22, 1907.
(Abst.) J. Soc. Chem. Ind., 1907, vol. XXVI, p. 415.

Dieterich, G.
The working of nickel ore deposits in New Caledonia.
Z. Vereins deutsch. Ing., 1907, vol. 51, No. 46, pp. 1805-1815, 1858-1867. (Profusely illustrated.)

Dow, H. H., Gates, W. S., and Schaeffer, A. E., Assignor to the Ontario Nickel Co.
Process of recovering the nickel in basic nickel precipitates.
U.S. Pat. 857927, June 25, 1907.
(Abst.) J. Soc. Chem. Ind., 1907, vol. 26, p. 880.

Ehrenfeld, C. H., and Grove, J. R.
Process for the recovery of nickel from ore.
U.S. Pat. 868769, Oct. 22, 1907.
(Abst.) J. Soc. Chem. Ind., 1908, vol. XXVII, p. 131.

Friedrich, K.
Nickel and arsenic.
Metallurgie, 1907, vol. IV, No. 7, pp. 200-216.

Gates, W. S., and Dow, H. H., Assignors to Ontario Nickel Co., Worthington (Can).
Process of rendering nickel and copper in sulphide ores and mattes soluble in water.
U.S. Pat. 874496, Dec. 24, 1907.
(Abst) J. Soc. Chem. Ind., 1908, vol. XXVII, p. 80.

Günther, E., and Franke, R., Eisleben (Germany).
Method of extracting copper-nickel ores and matte.
U.S. Pat. 875259, Dec. 31, 1907.
(Abst.) J. Soc. Chem. Ind., 1908, vol. XXVII, p. 131.
Same as German Pat. 199554, Apr. 3, 1906.
(Abst.) Fischer's Jahresbericht. Chem. Technologie, 1908, vol. 54, I, pp. 270-272.
Z. angew. Chemie, 1908, vol. XXI, p. 1998.

Meeks, R.
Nickel and cobalt.
Mineral Industry for 1907, vol. XVI, pp. 733-742.

Pring, J. N., Assignor to E. A. Sperry, Brooklyn.
Electrolytic process for refining nickel.
U.S. Pat. 874864, Dec. 24, 1907.
(Abst.) J. Soc. Chem. Ind., 1908, vol. XXVII, p. 343.

Schnabel, C.
Handbook of metallurgy.
London, 1898, Macmillan & Co., vol. II, pp. 496-596.
The most complete monography on nickel ever published. Patent literature fully taken into account.

Schreiber, G.
Separation of cobalt, nickel, and manganese from crude liquors.
German Pat. 203310, Sept. 29, 1907.
(Abst.) J. Soc. Chem. Ind., 1908, vol. XXVII, p. 1158.
Fischer's Jahresbericht Chem. Technologie, 1908, vol. 54, I, p. 268.

Sjöstedt.
The working of nickel-bearing pyrrhotite (magnetkies) in the electric furnace for the production of acid and ferro-nickel.
Glückauf, 1907, vol. 43, pp. 1042-1046.

Sperry, E. S.
The production of malleable nickel.
Brass World & Plater's Guide, 1907, Jan., vol. III, pp. 3-10.
(Abst.) J Soc. Chem. Ind., 1907, vol. 26, p. 530.
Metallurgie, 1907, vol. IV, pp. 155, 156.
Fischer's Jahresbericht u. Chem. Technologie, 1907, vol. 53 (Unorg. Teil), pp. 235, 236.

Stokes, R.
The Sudbury nickel-copper field.
Min. World, 1907, vol. 27, pp. 507-510, 799-801.

Willson, T. L., Ottawa (Ontario).
Method of producing metallic silicid.
U.S. Pat. 847300, Mar. 12, 1907.

Willson, T. L, Ottawa (Ontario).
Method of producing metallic silicides.
U.S. Pat. 847267, Mar. 12, 1907.

Woltmann, W., and Mostowitch, W.
Temperature measurements with the Wanner pyrometer (temperatures of molten nickel matte).
Metallurgie, 1907, vol IV, pp. 799, 800.
(Abst.) Fischer's Jahresbericht u. Chem. Technologie, 1907, vol. 53 (Unorg. Teil), p. 236.

1908—Nickel and cobalt.
Mineral Industry, 1908, vol. XVII, pp. 663-672.
A complete bibliography for 1908 is appended.

Armstrong, E. C.
Process for treating complex cobalt ores and for refining cobalt from nickel, arsenical and silver-bearing ores.
U.S. Pat. 881527, Mar. 10, 1908.

Bornemann, K.
The fusion diagram of nickel-sulphur compounds. The constitution of nickel matte.
Metallurgie, 1908, vol. V, pp. 13-19, 61-68.
(Abst.) J. Soc. Chem. Ind., 1908, vol. XXVII, pp. 1067, 1068.

Carrick, J. T., and Pattison, B. S.
Treating pyritic copper and nickel ores.
British Pat. 2971, Feb. 10, 1908.
(Abst) J. Soc. Chem. Ind, 1908, vol. XXVII, p. 1209.

Chalas, A., Philadelphia.
Process of recovering nickel from silicious ores.
U.S. Pat. 887735, May 12, 1908. French Pat. 393991, Sept. 5, 1908.
British Pat. 18596, Sept. 4, 1908.
Abst, J. Soc. Chem. Ind., 1908, vol. 27, p. 631.

Coleman, A P.
The Sudbury nickel ores.
Geol. Mag., vol. 5, 1908, pp. 18, 19.

Dow, H. H., and Gates, W. S
Assignors to Ontario Nickel Co., Ltd., Worthington (Can.).
Process of purifying precipitates.
U.S. Pat. 883792, Apr. 7, 1908.

Foote, H. W., and Smith, E. K.
Dissociation pressures of certain oxides of copper, cobalt, nickel, and antimony.
J. Amer. Chem. Soc., 1908, vol. 30, pp. 1344-1350.

Gregory, J. W.
Origin of the Sudbury nickel ores.
Geol. Mag., 1908 (new series), vol. 5, pp. 139, 140.

Gunther, E., and Franke, R., Eisleben (Germany).
Process of treating metallic ores or mattes
U.S. Pat. 879633, Feb. 18, 1908.

Ipatiew, W.
Reduction and oxidation of nickel oxides at various pressures.
Jour. prakt. Chemie, 1908, vol. 77, pp.. 513-532.
J. Soc. Chem. Ind., 1908, vol. XXVII, p. 684.

Koehler, W.
Recovery of nickel from oxide and silicate ores.
Electrochem. Met Ind., 1908, Apr., vol. VI, pp. 145-147.

Neil, J. M., Toronto, Assignor to F. C. Norris, Detroit (Mich.).
Separating the metals contained in copper-nickel matte.
U.S. Pat. 882075, Mar. 17, 1908.
(Abst.) J. Soc. Chem. Ind., 1908, vol XXVII, p. 411.

Roux, A. J., and Société "Le Nickel" de la Nouvelle Calédonie.
Process for obtaining nickel and nickel alloys from the natural nickeliferous, iron-magnesium hydrosilicates known as garnierite.
French Pat. 399412, Apr. 21, 1908.
Abst., J. Soc. Chem. Ind., 1909, vol. 28, No. 18, p. 990.

Rzehulka, A.
The present status of the production of nickel, with particular reference to the metallurgical practice as carried out at Frankenstein, Silesia.
Sammlung Berg- und Hüttenmännischer Abhandlungen, No. 32, 1908, 58 pp.

Savelsberg, J., Papenburg (Germany).
Blowing of nickel and cobalt matte in the converter, with a view to the preparation for subsequent melting.
German Pat. 222231, Jan. 21, 1908.
(Abst.) J. Soc. Chem. Ind., 1910, vol. 29, p. 1257.
Fischer's Jahresbericht, 1910, vol. 56, pp. 243, 244.

Société Electro-Métallurgique Francaise.
Production of pure nickel.
French Pat. 400910, June 27, 1908. British Pat. 14946, June 26, 1909.
(Abst.) J. Soc. Chem. Ind., 1909, vol. 28, p. 1090.

Stewart, L.
The Creighton mine, Sudbury.
Jour. Can. Min. Inst., 1908, vol. 11, pp. 567-585.

Stutzer, O.
The nickel-ore deposits of Sudbury (Ontario).
Zeits. f. prakt. Geol., 1908, vol. 16, pp. 285-287.

Wadhams, A. J., Riverton and Stanley, R. C., Assignors to International Nickel Co., Bayonne.
Art of separating metals from matte—Art of separating metals from speiss.
U.S. Pats. 900452, 900453, and 900454, all of Oct. 6, 1908.

Wallace, J. P.
A study of ore deposits for the practical miner.
1908, pp. 66-70

Wood, E. F., Assignor to International Nickel Co., N.J.
Process of utilizing flue-dust from copper and nickel ores.
U.S. Pat. 884970, Apr. 14, 1908.
(Abst.) J. Soc. Chem. Ind., 1908, vol. XXVII, p. 509.

1909—Betts, A. G., Troy (N.Y.).
Process of treating nickel ores.
U.S. Pat. 923005, May 25, 1909.
Abst., J. Soc. Chem. Ind., 1909, vol. 28, p. 661.

Browne, D. H., Copper Cliff, Ontario (Canada).
Method of manufacturing nickel and nickel-copper alloys.
U.S. Pat. 934278, Sept. 14, 1909.

Carrick, J. T., and Pattison, B. S., Johannesburg.
Treatment of pyritic copper and copper nickel ores.
British Pat. 13849, June 12, 1909. U.S. Pat. 939947, Nov. 9, 1909, and 947789, Feb. 1, 1910.
Abst., J. Soc. Chem. Ind., 1910, vol. 29, p. 284.

Cito, C. C., Irvington (N.J.).
Method for working ores consisting of compounds of silver, nickel, cobalt, these ores having arsenic but no lead.
British Pat. 30377, Dec. 29, 1909.
German Pat. 238608, Dec. 30, 1909 (Class 40c).
Abst., Z. angew. Chemie, 1911, vol. XXIV, No. 44, p. 2120.
J. Soc. Chem. Ind., 1910, vol. 29, p. 361.
Same as U.S. Pats. 949058 and 949261, Feb. 15, 1910.

Harker, A.
The Natural History of Igneous Rocks, 1909.

Horton, F. W.
Nickel and cobalt.
Mineral Industry for 1909, vol. XVIII, pp. 544-551.

Lambris, G.
Investigation into the absorption of carbon by metals during the electrolysis from aqueous solution, with particular reference to nickel.
Doctor thesis, presented at the Technische Hochschule, Aix-la-Chapelle (Germany). Published by La Ruelle'sche Akzideuzdruckerei (Inh. Jos. Deterrc), Aix-la-Chapelle, 1909.

Pécourt, B.
Method of concentrating those minerals containing metals (e.g. nickel and cobalt) which can be extracted by converting their sulphides into soluble sulphates by roasting.
French Pat. 403831, June 9, 1909.
Abst., J Soc. Chem. Ind., 1910, vol. 29, p. 97.

Pitavel, R.
The electrometallurgy of nickel.
Jour. Four Electrique et de l'Electrolyse, 1909, July 15.

Price, E. F., Assignor to Central Trust Co., New York.
Process of obtaining nickel from silicious ores.
U.S. Pats. 909666 and 909667, Jan. 12, 1909.

Schenck, R
Chemical equilibria in metallurgical reactions.
Metallurgie, 1909, vol. VI, No. 16, pp. 505-511.

Schmidt, C, and Verloop, J. H.
Note on the deposit of cobalt and nickel ores near Schladming (Steiermark).
Zeits. f. prakt. Geologie, 1909, June, vol. 17, pp. 271-275.
(Paper contains a complete bibliography.)

Schweitzer, Alex.
Contribution to the knowledge of the electrochemical behavior of nickel.
Thesis presented in 1909 to the Technische Hochschule, Dresden.
(Printed by Buchdruckerei Chr. Scheufele, Stuttgart.)

Société Electro-Métallurgique Francaise.
Process for obtaining pure nickel.
First addition, dated Jan. 6, 1909, to French Pat. 400910, June 27, 1908.
British Pat. 287, Jan. 5, 1910.
(Abst.) J. Soc. Chem. Ind., 1910, vol. 29, p. 636.

Sylvester, G. E.
The mining, smelting and power plants of the Canadian Copper Co.
Jour. Canadian Min. Inst., 1909, vol. XII, pp. 218-239.

Vogt, J. H. L.
Work referred to in The Natural History of Igneous Rocks by A. Harker, 1909, p. 174.

Van Hise, C. R., Leith, C. K.
Geology between lake Timagami and Onaping river.
Bull. 360, U.S.G.S., 1909, pp. 428, 429.

Van Hise, C. R., Seaman, A. E.
Examination of rocks at Sudbury.
Bull. 360, U.S.G.S., 1909, pp. 424, 425.

Warlimont, F.
On the oxidation of sulphides and dissociation of sulphates of iron, copper and nickel and a simple method, based on these experiments, for smelting pyrrhotites (magnetkies) containing copper and nickel.
Doctor thesis, presented in 1909 to the Technische Hochschule, Aix-la-Chapelle (Germany).
(Verlag von W. Knapp, Halle a-S.)

Warlimont, F.
A process for smelting pyrrhotites containing copper and nickel.
Metallurgie, 1909, vol. VI, No. 3, pp. 83-92; No. 4, pp. 127-134.

Wells, H. L., New Haven (Conn.).
Method of separating copper nickel and other metals from copper-nickel matte, and recovering hydrochloric acid from nickel chloride solution.
U.S. Pats. 940292 and 940293, Nov. 16, 1909,
(Abst) J. Soc. Chem. Ind., 1910, vol. 29, p. 30.

Nickel and cobalt.
Mineral Industry for 1910, vol. 19, pp. 501-506.

1910—Anonymous.
Electric smelting of nickel ore.
(A new electric furnace plant for nickel silicide at Webster, Jackson County, N.C.).
Met. Chem. Engng., 1910, May, vol. VIII, pp. 277-279.

Anonymous.
Norwegian nickel, copper and sulphur mines.
Foreign Office (London), Annual Series, 1910, October.
(Abst.) J. Soc. Chem. Ind., 1910, vol. 29, p. 1458.

Anonymous.
The nickel industry.
Times Engng Supplement (London), July 20, 1910.
Canadian Min. Jour., 1910, Oct. 1, v. 31, pp. 589, 590.

Barton, Th., and McGhie, Th. B.
Separation of cobalt from nickel in solutions containing mixtures of their chlorides.
German Pat. 222141.
Abst., Metallurgie, 1910, vol. VII, p. 621.

Bornemann, K.
The system Ni-S. (II).
Metallurgie, 1910, vol. VII, pp. 667-674.

Browne, D. H.
Behavior of copper-matte and copper-nickel matte in the Bessemer converter.
Bull. Amer. Inst. Min. Engrs., 1910, No. 40, pp. 285-305.

Chalas, A., Philadelphia (Pa.).
Process of recovering nickel and copper from ores and mattes.
U.S. Pat. 947791, Feb. 1, 1910.
(Abst.) J. Soc. Chem Ind, 1910, vol. 29, p. 284.

Chalas, A., Philadelphia, (Pa.).
Process of reducing nickel hydrosilicate ores.
U.S. Pat. 959460, May 31, 1910.
(Abst.) J. Soc. Chem. Ind., 1910, vol. 29, p. 826.

Cinille, H. A. G.
Direct manufacture of copper, nickel and other metals.
French Pat. 421990, Oct. 29, 1910.
(Abst.) J. Soc. Chem. Ind., 1911, vol. 30, p. 553.

Cito, C. C.
A new process for the treating of cobalt-nickel ores, rich in silver and arsenic by combined melting and electrolytic operations.
Trans. Amer. Electrochem. Soc., 1910, vol. XVII, pp. 239-248.
Met. Chem. Engng., 1910, vol. VIII, pp. 341-344.

Coleman, A. P.
The Alexo nickel deposits.
Economic Geology, 1910, June, vol. V, pp. 372-376.

Coleman, A. P.
Copper and nickel deposits of Canada.
Abstract, British Ass. Adv. Sci., 1910, Rept. 79th meeting, pp. 479, 480 .

Dewey, F. P., Assignor to Dewey Ore Reduction Corporation.
Process for treating arsenid ores.
U.S. Pats. 954263 and 954264, Apr. 5, 1910.

Friedrich, K., and Leroux, A.
Freezing point diagram of nickel-carbon alloys.
Metallurgie, 1910, vol. VII, pp. 10-13.
(Abst.) J. Soc. Chem. Ind, 1910, vol.. 29, p. 159.

Gray, Alex.
Nickel-copper industry of Ontario.
Mining World, 1910, May 14, pp. 973-977; May 21, pp. 1019-1025, vol. XXXII; May 28, pp. 1065-1070.
Of the greatest importance from the point of view of history.

Laszynski, S.
Precipitation of metals, especially of zinc, copper and nickel from sulphuric or sulphurous acid solutions.
German Pat. 257647, Nov. 20, 1910.
(Abst.) J. Soc. Chem. Ind., 1913, vol. XXXII, p. 492.

Mackenzie, G. C
Magnetic concentration experiments with iron ores of the Bristol Mines, Que, iron ores of the Bathurst Mines, New Brunswick, a copper nickel from Nairn, Ontario.
Canada, Department of Mines, Mines Branch, 1910, Bulletin No. 5, pp. 17-28.

Shipley, G. B.
Mining and smelting plant of Mond Nickel Co.
Engng. & Min. Jour., vol. 90, Aug. 20, 1910, pp. 364-367.

Shuler, D. P., Sudbury (Ontario).
Separation of nickel and copper from mattes.
U.S. Pat 967072, Aug. 9, 1910.

Nickel and cobalt.
Mineral Industry for 1911, vol. XX, pp. 547-553.

1911—Babé, J., and Collin, M.
Process for obtaining nickel from its oxidized ores.
French Pat. 449112, Dec. 13, 1911.
Abst., Metall. u. Erz., 1913, vol. I, p. 468.
J. Soc. Chem. Ind., 1913, vol. 32, p. 494.

Borchers, W.
Metallurgy.
** A brief outline of the modern processes for extracting the more important metals.
Authorized translation from the German by W. T. Halle and C. R. Hayward.
1st edition, 1911, pp. 100-176.
(A well written, concise account of modern practice; no historic details are given.)

Borchers, W., and Pedersen, H. (Trowdhjern).
Process for the extraction of copper and nickel, particularly from low grade ores.
French Pat. 437774, Dec. 18, 1911. German Pat. 245198, Mar. 23, 1911.
U S Pat. 1043291, Nov. 5, 1912. British Pat. 227, Jan. 3, 1912.
Abst., J. Soc. Chem. Ind., 1912, vol. 31, p. 497.
Metall. u. Erz., 1912-1913, vol. I, p. 21.
Chem. Abst., 1912, vol. VII, p. 2039.

Borchers, W., and Pedersen, H. (Trowdjhern).
Process for the treatment of sulphide nickel ores or metallurgical products containing iron and copper.
German Pat. 248802, Dec. 30, 1911 (Addition to German Pat. 245198, Mar. 23, 1911).
British Pat. 9146, Apr. 18, 1912 (Addition to British Pat. 227, 1911).
U.S. Pat. 1101115, June 23, 1914.
Abst., J. Soc. Chem. Ind., 1912, vol. 31, No. 19, p. 933.
Metall. u. Erz., 1912-1913, vol I, pp. 125, 126.

Browne, D. H.
The history of the nickel industry in Canada and the United States.
Jour. Soc. Chem. Ind, Mar. 15, 1911, vol. 30, pp. 248-250.
Metallurgie, 1911, vol. VIII, pp. 438-441.
Can. Min. Jour., 1912, Dec. 1, vol. 33, pp. 817-819.

Carpenter, F. R., and Carpenter, A. H., Denver.
Process for freeing sulphide copper-nickel-iron ores and mattes derived therefrom from their copper contents
U S Pat. 1006355, Oct 17, 1911.
Abst., J. Soc. Chem. Ind., 1911, vol. XXX, p. 1319.

Crane, W. R.
Filling methods at Sudbury.
Engng. Min. Jour., 1911, June 17, vol. 91, pp. 1204-1207.

Dammer, O.
Chem. Technologie der Neuzeit.
Stuttgart, Verlag von Ferd. Enke, 1911.
Lange, A.: Chapter on nickel and cobalt, pp. 433-462.

Dow, H. H., Gates, W. S., and Schaefer, A. E., Assignors to the Ontario Nickel Co., Ltd., Worthington.
Method of electrolyzing nickel sulphate solutions.
U.S. Pat. 1003092, Sept. 12, 1911.

Gabrielli, C.
Process for the purification of mattes of metals of the nickel group.
French Pat. 444067, July 29, 1911.
(Abst.) J. Soc. Chem. Ind, 1912, vol. 31, pp. 1134.

Hugoniot, C. E.
Process for the magnetic enrichment of complex ores, more especially the nickel ores of New Caledonia.
French Pat. 449301, Dec. 19, 1911.
(Abst.) J. Soc. Chem. Ind., 1913, vol. 32, p. 494.

Kern, E. F., and Walter, H. W.
Roasting of nickel copper matte.
School of Mines Quarterly, 1911, vol. 32, pp. 364-388.

McKechnie, A., and Beasley, F. G.
Method of treating high-grade nickel-copper mattes, practically free from iron.
British Pat. 15850, July 8, 1911. French Pat. 441785, Mar. 27, 1912.
U S. Pat. 1047825, Dec. 12, 1912. Canadian Pat. 143074, Oct. 1, 1912.
German Pat. 247968, July 16, 1911.
Abst., J. Soc. Chem. Ind., 1912,, vol. 31, No. 16, p. 780.
Chem. Abst., 1912, vol. VI, p. 2734
Metall u. Erz., 1912-1913, vol. I, p. 149.
Fischer's Jahresbericht, 1912, vol. 58, 1, p. 296.

McLarty, J. A., Toronto (Canada).
Treatment of sulphide ores.
U.S Pat. 987156, Mar. 21, 1911.
(Abst.) J. Soc. Chem. Ind., 1911, vol. 30, p. 494.

McLeish, John.
Mineral production of Canada in 1910.
Engng. Min. Jour., 1911, vol. 91, pp. 512, 513. (Statistical data.)

Miller, Willet G.
Notes on the Cobalt area.
Eng. and Min. Jour., 1911, Sept. 30, pp. 645-649. (The name Timiskaming was first proposed in this paper by the author.)

Morrison, W. L.
Electric furnace treatment of nickel ore and the development of a commercial process.
Trans. Amer. Electrochem. Soc., 1911, vol. XX, pp. 315-358.
Met. Chem. Engng., 1911, vol. IX, pp. 546-552.
(Abst.) J. Soc. Chem. Ind., 1911, vol. 30, p. 1260.

Pedersen, H.
Investigation of cobalt, nickel and cobalt ores.
(Separation of nickel from copper, cobalt, and iron.)
Metallurgie, 1911, vol. VIII, p. 335.
(Abst.) J. Soc. Chem. Ind., 1911, vol. 30, p. 900.

Rennie, W D., Hackensack, Assignor to Universal Ore Reduction Co., Phoenix (Ariz.).
Art of extracting metals, such as gold, silver, copper or nickel, from their native ores.
U.S. Pat. 989802, Apr. 18, 1911.

Uglow, W. L.
The Alexo Mine: A new nickel occurrence in northern Ontario.
Can. Min. Inst. Jour. Oct., 1911, No. 16, pp. 151-173.

1912—Anonymous.
Les Exploitations Minières de Nickel de la Dumbéa.
Bull. du Commerce N. Caledonie, June 22, 1912, p. 9 et seq.

Anonymous.
Nickel smelter at Thio, New Caledonia.
Bull. Commerce de la Nouvelle-Caledonie.
Min. Engng. World, 1912, Apr. 27, vol. 36, p. 902.

Apgar, F. W., and Thomas, K.
Occurrence of pentlandite in the Sudbury ores.
Met. Chem. Engng., 1912, Nov., vol. X, p. 744.

Bancroft, H.
A nickel deposit in the San Poil mining district, Washington.
Min. Sci. Press, 1912, vol. 104, pp. 144, 145.

Barth, O.
Metallurgical treatment of a roasted cobalt-nickel speiss containing much lead.
Metallurgie, 1912, vol. IX, pp. 199-216.
(Abst.) Chem. Abst., 1912, vol. VI, p. 1732. J. Soc. Chem. Ind., 1912, v. 31, p. 391.

Borchers, Gebr., Goslar am Harz (Germany).
Process of treating ores and smelting products containing cobalt, nickel and silver.
British Pat. 18276, Aug. 8, 1912.
(Abst.) J. Soc. Chem. Ind., 1913, vol. XXXII, p. 980.

Browne, D. H.
New smelting plant of the Canadian Copper Co.
Bull. Canadian Mining Inst., 1912, vol. 15, pp. 33-40.
Min. Engng. World, 1912, vol. XXXVI, pp. 597, 598.
Trans. Canadian Mining Inst., 1912, vol. XV, pp. 115-122.

Collins, W. H.
Geology of Onaping sheet, Ontario.
Canada Geol. Survey, Summary Report for 1912, Sessional paper No. 26, pp. 307, 308.

Du Toit, A. L.
The copper-nickel deposits of the Insizwa, East Griqualand.
South African Min. Jour., 1912, Mar. 9, vol. X, pp. 19, 20.

Fink, C. G.
Vacuum furnace metallurgy.
Trans. Amer. Electrochem. Soc., 1912, vol. XXI, pp. 445-452.
Met. Chem. Engng., 1912, vol X, p. 296.

Hoffman, H. O., and Wanjukow, W.
Decomposition of some metallic sulphates (e.g., $NiSO_4$) at an elevated temperature in a current of air.
Met. Chem. Engng., 1912, vol. X, p. 172.

Hore, R. E.
Origin of the Sudbury nickel and copper deposits.
Min. Engng. World, 1912, vol. 36, pp. 1345-1349.

Maxwell, H.
Exploring the Sudbury ore bodies.
Engng. & Min. Jour., Aug. 3, 1912, vol. 94, No. 5, p. 206.

Mehereng, P. A. de.
Extraction of pure nickel from garnierite (hydrosilicate of nickel and magnesium).
French Pat. 441074, Mar. 7, 1912.
(Abst.) J. Soc. Chem. Ind., 1912, vol. 31, p. 824.

Rossi, A. J., Niagara Falls, Assignor to the Titanium Alloy Manufacturing Co., New York.
Method of purifying and improving nickel.
U.S. Pat. 1020513, Mar. 19, 1912.

Ruff, O.
Equilibrium diagrams of carbon with iron, nickel, cobalt, and manganese.
Ber., 1912, vol. 45, pp. 3139-3148.
(Abst.) J. Soc. Chem. Ind., 1912, vol. 31, pp. 1130, 1131.

Stephan, M.
A few notes on the production of metals in the electric furnace.
Metall. u. Erz, 1912-1913, vol. I, pp 11-17; discussion, pp. 84-86.
Jour. Four electrique et de l'Electrolyse, 1913, Feb. 1, vol. XXII, pp. 52, 53.

Sulman, H. L., Picard, H. F. K., and Roberts, A. E., London.
(Madagascar Minerals Syndicate, Ltd.)
Recovery of nickel from its ores.
British Pat. 27626, Nov. 30, 1912, No. 3814, Feb. 14, 1913, and 6703, Mar. 18, 1913. French Pat. 463615, Dec. 21, 1912. First addition, dated Feb. 15, 1913, to French Pat. 463615, Dec. 21, 1912.
Abst., J. Soc. Chem. Ind., 1914, v. 33, p. 30.

Thomas, K.
The Sudbury nickel district, Ontario, Can.
Min. Sci. Press, 1912, Oct. 5, vol. 105, p 433.

Wells, H. L., New Haven, Assignor to M. H. King, East Orange (N.J.).
Process of extracting nickel (by leaching).
U.S. Pat. 1044316, Nov. 12, 1912.
(Abst.) J. Soc. Chem. Ind., 1912, vol. 31, p. 1186.
Metall. u. Erz., 1912-1913, vol. I, p. 634.

Anonymous.
The Silesian garnierite deposits.
Kohle. u. Erz., 1913, No. 25.
Abst., Metall. u. Erz, 1912-1913, vol. I, pp. 788, 789.

1913—Anonymous (Special Correspondence).
Nickel Development at Sudbury, Ont.
Engng.. & Min. Jour., Aug. 2, 1913, vol. 96, No. 5, pp. 205, 206.

Anonymous.
Electrolytic nickel smelting in Norway. (Daily Consular Report.)
Brass Wld. & Plater's Guide, 1913, vol. 7, p. 429.

Anonymous.
Nickel in South Africa.
(Reported discovery of extensive deposit.—Some account of the Canadian fields.)
South African Min. Jour., 1913, Aug. 16, vol. 22, pp. 642, 643.

Economic minerals and mining industries of Canada.
Canada, Dept. of Mines, Mines Branch, Publication No. 230, 1913, pp. 29-31: Nickel.

Anonymous.
Sorting, roasting and smelting nickel-copper ore, Canadian Copper Co.
Can. Mining Jour., 1913, Aug. 1, vol. 34, pp. 482-488. (Profusely illustrated.)

Bonnefond, F.
Note on certain mineral products found in Madagascar.
Mémoires Soc. Ingénieurs Civils de France, 1913, I, p. 102.

Borchers, W., and Thilges, E.
Separation of iron and nickel from cupriferous sulphide ores and metallurgical products (mattes).
German Pat. 271595, Aug. 1, 1913. British Pat. 9535, Apr. 17, 1914.
(Abst.) J. Soc. Chem. Ind., 1914, vol. 33, p. 488.

Brackenbury, C.
Notes on the rocks at Levack, Ontario.
Ontario, Report Bureau of Mines, 1913, vol. 23, part I, pp. 194-201.

Burgess, G K, and Waltenberg, R. G
Melting points of the refractory elements.
I. Elements of atomic weight from 48-59.
Jour. Washington Acad. Sciences, 1913, vol. III, pp. 371-378.

Burlet, L. J. G. de, Hoboken (Belgium).
Process of extracting cobalt or nickel and copper from cobalt or nickel-bearing copper.
British Pat. 27150, Nov. 25, 1913.
(Abst.) J. Soc. Chem. Ind., 1914, vol. 33, p. 1014.

Coleman, A. P.
Classification of the Sudbury ore deposits.
Trans. Canadian Min. Inst., 1913, vol. XVI, pp. 283-288.

Coleman, A. P.
The nickel deposits of Sudbury district.
Canadian Min. Jour., 1913, Sept. 1, vol. 34, p. 552.

Coleman, A P.
The nickel industry: with special reference to the Sudbury region, Ont.
Canada, Department of Mines, Mines Branch, Bull. No. 170, 198 pp.

Coleman, A. P.
Nickel smelting by the Mond Process.
Can. Dept. of Mines, Bull. 170.
Min. Sci. Press, 1913, Sept. 13, vol. 107, pp. 412-417.

Coleman, A. P.
The Massey copper mine area, Ontario.
Ontario Report of the Bureau of Mines, 1913, vol. 22, part I, pp. 155-160, 146-154.
The Sudbury series, Sudbury.
Congrès Geologique International, Compte-Rendus de la, 12th Session, 1913, pp. 387-398.
The Geology of Sudbury.
Guide Book No. 7, Ibid.

Collins, W. H.
Geology of a portion of Sudbury map-area, south of Wanapitei lake, Ont.
Can. Geol. Survey, Summary Report for 1913, Sessional paper, No. 26, pp. 190, 191.

Collins, W. H.
Classification of the pre-Cambrian formations in the region east of lake Superior.
Congrès Geologique International, Compte-Rendus de la, 12th Session, 1913, pp. 399-407.

Fierz, H. E., Basle (Switzerland), and Cohen, E., London.
Extraction of nickel from mixtures of nickel and other metals, as carbonyl.
British Pat 4249, Feb. 19, 1913. U.S. Pat 1103747, July 14, 1914.
(Abst.) J. Soc. Chem. Ind., 1913, vol. 32, p. 870
Chem. Abst., 1913, vol. VIII, p. 2668.

Friedrich, K.
Contribution to the knowledge of the freezing points of cobalt-nickel arsenides.
Metall. u. Erz., 1913, vol. 10, pp. 659-671.

Hore, R. E.
Sudbury nickel-copper industry.
(Extent of the deposits Methods of mining the ore, heap roasting, and smelting to matte)
Mines & Minerals, 1912-1913, Feb., vol. 33, pp 383-385.

Hore, R. E.
Magmatic origin of Sudbury nickel-copper deposits.
Trans Can. Min Inst., 1913 (March), vol. XVI, pp. 271-282.
Can. Min. Jour., 1913, July 15, vol. 34, pp. 437-441.

Kern, E. F., and Merris, H. M.
The roasting of copper-nickel matte.
School of Mines Quarterly, 1913-1914, vol. 35, pp. 1-21.

Krauth, C.
The mineral wealth of the Caucasus.
Technische Blätter, 1913, Feb. 22, p. 57.

Launay, L. de.
Traité de métallugénie.
Gites minéraux et métallifères.
1913, Paris, Librairie Polytechnique Ch. Béranger, vol. II, pp. 573-604.
The author states that the metallurgy of nickel dates back only from 1824, when V. Gersdorff established the first plant in Austria.

Lindgren, W.
Mineral deposits.
1913, New York, pp. 324-326, 746, 795.

Madagascar Minerals Syndicate, Ltd.
Recovery of nickel from its ores.
Third addition, dated July 4, 1913, to French Pat. 463615, Dec. 21, 1912.
Same as British Pats. 27626 of 1912 and 3814 and 6703 of 1913.

Miller, Willet G.
The cobalt-nickel arsenides and silver deposits of Temiskaming.
Ontario, Report of the Bureau of Mines, 1913, vol. XIX, pt. 2, 279 pp.
The Cobalt area.
Congrès. Geol. Int., 1913, 12th Session Guide Book No. 7.

Miller, Willet G., Knight, Cyril W.
Sudbury, Cobalt and Porcupine geology.
Eng. Min. Jour., 1913, June 7, pp. 1129-1132.

Mineral Products, Ltd.
Process of disintegration of silicates (extraction of nickel from garnierite) by superheated steam.
French Pat. 458432, May 2, 1913.
(Abst.) J. Soc. Chem. Ind., 1913, vol. 32, p. 1108.

Mineral Products, Ltd., and H. C. Woltereck.
Extraction of metallic nickel from nickel ores.
French Pat. 460575, July 21, 1913.
(Abst.) J. Soc. Chem. Ind., 1914, vol. 33, p. 88.

Pedersen, H. (Trondhjern).
Studies regarding the simplification of the smelting of sulphide nickel ores and smelter products carrying iron and copper.
Metall. u. Erz., 1913, Apr. 8, vol. I, pp. 384-403.
Abst., Chem. Abst., 1913, vol. VII, pp. 2033, 2034.
J. Soc. Chem. Ind., 1913, vol. 32, p. 490.

Ruff, O., and Gersten, E.
Carbides of manganese and nickel.
Berichte, 1913, vol. 46, pp. 400-413.
(Abst.) J. Soc. Chem. Ind., 1913, vol. 32, p. 293.

Stephan, M.
Production of copper and nickel in the electric furnace.
Met. Chem. Engng., 1913, Jan., vol. XI, pp. 22, 23.

Sulman, H. L., Picard, H. F. K., and Roberts, A. E.
Recovery of nickel from its ores.
British Pats. 17131, Mar. 18, and 18769, Aug. 18, 1913.
(Additions to British Pat. 27626, Nov. 30, 1913.)
Second addition, dated Mar. 22, 1913, to French Pat. 463615, Dec. 21, 1912.
(Abst.) J. Soc. Chem. Ind, 1914, vol. 33, p. 489.
U.S. Pat. 1091545, Mar. 31, 1914.

Vuigner, J. B. M. E., and Pierron, P. R.
Method of preparation of nickel and its alloys.
French Pat. 455253, May 18, 1912.
(Abst.) J. Soc. Chem. Ind., 1913, vol. 32, p. 870.

Wells, H. L., and King, J. C.
Process for extracting nickel from matte.
U.S. Pat. 1067698, July 15, 1913.
(Abst.) Chem. Abst., 1913, vol. VII, p. 2923.
J. Soc. Chem. Ind., 1913, vol. 32, p. 832.

Wilson, A. W. G.
The copper smelting industries of Canada.
Canada, Dept. of Mines, Mines Branch, Publ. No. 206, 1913, pp. 31-60.
Description of the mining and smelting operations of the Canadian Copper Co., pp. 69-92: Mond Nickel Co., Ltd.

1914—Monell method of separating nickel and copper sulphides.
Canadian Min. Jour., 1914, Feb. 1, vol. 35, pp. 85, 86.

Berger, E.
Reduction by hydrogen of copper and nickel oxides in presence of a dehydrating agent.
Comptes-Rendus de l'Académie des Sciences, 1914, vol. 158, pp. 1798-1801.
(Abst.) J. Soc. Chem. Ind., 1914, vol. 33, p. 752.

Carpenter, A. H.
Chloridizing the Sudbury copper-nickel ores.
Engng. Min. Jour., 1914, May 30, vol. 97, pp. 1085-1089.

Coleman, A. P.
The Pre-Cambrian rocks north of Lake Huron, with special reference to the Sudbury series.
Ontario, Bureau of Mines, Twenty-third Annual Report, 1914, vol. XXIII, pp. 202-236.

Daly, R. H.
Igneous Rocks and their Origin, 1914, pp. 347-349, p. 455.

Dudley, B.
A study of the chloridizing roast and its application to the sepaiation of copper from nickel.
Bull.. Amer. Inst. Min. Engrs. 1914, Dec., No. 96, pp. 2767-2782.

Gowland, Wm.
The metallurgy of the non-ferrous metals.
London, Chas. Griffin & Co., 1914. (Book.)
Pp. 417-436: Nickel.

Hayward, C. R.
The equilibrium diagram of the system Cu_2S- Ni_3S_2.
Trans. Amer. Inst. Min. Engrs., 1914, vol. 48, pp. 141-152.

Hore, R. E.
Michigan copper deposits.
Mich. Geol. and Biol. Sur., 1914, Pub. 16, pp. 11-37

Howe, E.
Petrographical notes on the Sudbury nickel deposits.
Economic Geology, 1914, Sept., vol. IX, pp. 505-522.

Hybinette, N. W., Christiania.
Producing copper-nickel anodes; process of circulating solution for electrolysis Anode for electrolysis.
U.S Pats 1128314, 1128315, and 1128316, all of Feb 16, 1915.
British Pat. 13355, May 30, 1914 (Abst.) J. Soc Chem. Ind., 1915, v. 34, p. 364.

Sabatier, P. and Espil, L.
Reduction of the oxides of copper, lead and nickel.
Comptes-Rendus de l'Académie des Sciences, 1914, vol. 159, pp. 137-142.
(Abst.) J. Soc. Chem. Ind., 1914, vol. 33, pp. 1092, 1093.

St. Clair, St.
Origin of the Sudbury ore deposits.
Min. Sci. Press, 1914, Aug. 15, vol. 109, pp 243-246.

Thomas, K.
The Sudbury nickel district of Ont.
Engng. Min. Jour., Jan. 10, 1914, vol. 97, No. 2, pp. 152-154.

Turner, H. W.
Nickel deposits in the Urals.
Bull. Amer. Inst. Min. Engrs., 1914, Feb., No. 86, pp. 187-193.

Walker, T. L.
Temiskamite, a new nickel arsenide from Ontario.
Amer. Jour. Science, 1914, Feb., vol. XXXVII (4th Series), pp. 170-172.

Wilson, A. W. G.
The Mond Nickel Co.'s smelting plants at Victoria Mines and Coniston, Ont.
Can. Min. Jour., 1914, Oct. 15, vol. 35, pp. 667-671.

1915—Anonymous.
Manufacture of nickel in Canada.
U.S. Commerce Reports No. 187, Aug. 11, 1915.

Anonymous.
Canadian nickel production.
Engng. Mng. Jour., Aug. 21, 1915, vol. 100, No. 8, p. 300.
(Data furnished by Amer. Consul H. P. Starrett, Fort William, Ont.)

Aston, J.
Nickel and cobalt.
Mineral Industry, 1915, vol. XXIV, pp. 517-524.

Bowen, N. L.
The later stages of the evolution of the igneous rocks.
Jour. Geol., 1915, Nov.-Dec., Supplement, pp. 1-91.

Burrows, L. P.
Process for the extraction of nickel.
British Pat. 12358, Aug. 27, 1915.
Canadian Pat. 165916, Nov. 9, 1915. French Pat. 479606, Aug. 27, 1915.
Chem. Abst., 1917, vol. XI, No. 3, p. 246.
J. Soc. Chem. Ind, 1916, vol. 35, No. 20, p. 1066.

Coleman, A. P.
Discussion of Dr. Howe's paper entitled "Petrographic notes on the Sudbury nickel deposits."
Econ. Geol., 1915, vol. X, pp. 390-393.

Dudley, B., Jr.
A study of the chloridizing roast and its application to the separation of copper from nickel.
Trans. Amer. Inst. Min. Engrs., 1915, vol. 51, pp. 684-699.
Met. Chem. Engng., 1915, Mar., vol. XIII, No. 3, p. 181.

Hybinette, N. V., Kristianssands (Norway), Assignor to National Trust Co., Ltd, Toronto (Can.).
Separating copper from nickel and matte and other products.
U.S. Pat. 1128313, Feb. 16, 1915.

Johnston, R. A. A.
A list of Canadian mineral occurrences.
Can, Dept of Mines, Geol. Survey, Memoir No. 74 (No. 61, Geol. Series), pp 189-191: Occurrence of pyrrhotite, 1915.

Manz, H.
Roasting of copper-nickel ores.
Chem. Ztg, 1915, vol. 39, pp. 693, 694.
(Abst.) J. Soc. Chem. Ind., 1915, vol. 34, p. 1057.

Miller, Willet G., Knight, Cyril W.
Metallogenetic epochs in the pre-Cambrian of Ontario.
Report Ontario Bureau of Mines, 1915, vol XXIV, pp. 243-248 (A paper presented before the Royal Society of Canada, May, 1915.)
Revision of the pre-Cambrian classification in Ontario.
Jour. Geol., 1915, vol. XXIII, Oct.-Nov., pp. 585-599.
Revision of the pre-Cambrian classification in Ontario.
Can. Min. Jour, 1915, May 1, vol. XXXVI, pp. 265, 266.
Abstract: Revision of the pre-Cambrian classification in Ontario.
Geol. Soc. Am. Bull., 1915, vol. XXVI, Mar. 31, pp. 87, 88.
Abstract: Revision of the pre-Cambrian classification in Ontario.
Science, New Ser, 1915, vol. 41, p. 509, April 2.
Abstract: Pre-Cambrian ore deposits in Ontario.
Min. and Sci. Press, 1915, vol. III, Sept., pp. 401-404.

Ruff, O., Bormann, W., and Keilig, F.
Manganese, nickel, iron and cobalt, respectively, and carbon.
(Researches in the field of high temperatures.)
Z. anorg. Chemie, 1914, vol. 88, pp. 365-423.
(Abst.) J. Soc. Chem. Ind., 1915, vol. 34, p. 84.

Walker, T. L.
Certain mineral occurrences in the Worthington mine, Sudbury (Ont.), and their significance.
Econ. Geology, 1915, Oct., vol. X, pp. 536-542.

White, A. G.
Tasmanian nickel deposits.
Mining Mag, 1915, Feb., vol. 12, pp. 103-105.

1916—Recent developments in the Sudbury district, Ont.
Can. Mng. Jour., Aug. 15, 1916, v. 37, No. 16, pp. 391, 392.

Occurrence and utilization of nickel ores.
Bull. Imperial Inst., 1916, vol. XIV, pp. 228-253.

Beyschlag, F., and Vogt, J. H. L.
The deposits of the useful minerals and rocks. (Their origin, form and content.)
Translated from the German by S. J. Truscott, 1916, London, vol. II, pp. 945-949: The nickel-cobalt arsenide lodes, pp 950-962: The nickel-silicate or garnierite deposits, pp. 962, 963, vol. I, pp. 280-299.

Calkins, F. C.
Molybdenite and nickel ore in San Diego County, Cal.
U.S. Geol. Survey, 1916, Bull. 640-D.
(Abst.) Engng. Min. Jour., 1916, vol. 102, No. 7, pp 310, 311.

Coleman, A. P.
Geological relations of the Sudbury nickel ores.
Engng. Min. Jour., 1916, vol. 102, pp. 104, 105.

Coleman, A P.
Chief minerals of the Sudbury nickel ores.
Can. Mng. Jour., Aug. 15, 1916, v. 37, No. 16, p. 388.

Corless, C. V.
Origin of Sudbury nickel-copper deposits.
Engng. Min. Jour., 1916, Sept. 16, vol. 102, No. 12, pp. 517, 518

Eustis, F. A.
Treating nickel ores.
British Pat. 101285, June 28, 1916.
(Abst.) Chem. Abst., 1917, vol. XI, No. 1, p. 31.

Goodchild, W. H.
The economic geology of the Insizwa range, South Africa.
Inst. Min. and Metallurgy, London, Bull. 147, Dec. 14, 1916, pp. 43-47.

Guillet, L.
A comparative study of French and foreign metallurgical methods.
II. Metallurgy of the non-ferrous metals (e.g., Ni).
Bull. Soc. d'Encouragement pour l'Industrie Nationale, 1916, vol. 126, pp. 201-296.

Harker, A.
Differentiation in intercrustal magma basins.
Jour. Geol., 1916, vol. 24, Sept.-Oct., pp. 554-558.

Knight, Cyril W.
Origin of the Sudbury nickel deposits.
Engng. Min. Jour., 1916, May 6, vol. 101, pp. 811, 812. (Paper reviewed in Min. Mag., London, June, 1916, vol. 14, pp. 307, 348, 349. Can. Min. Jour., Aug. 15, 1916, p. 390.)

Knight, Cyril W.
Geological relations of Sudbury nickel ores.
Engng. Min. Jour., 1916, Sept. 23, vol. 102, No. 13, pp. 554, 555.

Leonard, R. W.
Nickel refining in Canada.
Can. Mng. Inst. Bull, Sept., 1916, No. 53, p. 758 et seq.

Lotti, Alfredo.
Notizie Complementari sulla Metallurgia del Nickel in America.
Metallurgica (Ital.), July 15, 1916.

Parodi, Lorenzo.
Notizie Sulla Metallurgia del Nickel Importanza del Nickel Nell-ocherna metallurgia.
Metallurgia (Ital.), May 31, 1916, p. 355.

Ries, H.
Economic geology.
1916, New York, 4th ed., pp. 794-805.

Sulman, H. L., and Picard, H. H. R., Assignors to the Madagascar Minerals Syndicate, Ltd., London.
Recovery of metals from its ores.
U.S. Pat. 1193734, Aug. 8, 1916.
Norwegian Pat. 27235, Aug. 28, 1916.
(Abst.) Chem. Abst., 1916, vol. X, No. 23, p. 3058.

Tolman, C. F., and Rogers, Austin F.
A study of the magmatic sulphide ores.
Leland Stanford Junior Univ. Publ., 1916

1917—Goodchild, W. H.
Discussion on the geology of the Insizwa range, South Africa, and on the geology of Sudbury, Ontario.
Inst. Min. and Met., London, Jan. 11, 1917, Bulletin No. 148, pp. 1-11.

Tolman, Jr., C. F., and Rogers, Austin F.
The origin of the Sudbury nickel ores.
Engng. & Mng. Jour., vol. 103, Feb 3, 1917, pp. 226-229.

APPENDIX I.

OFFICIAL CANADIAN PUBLICATIONS MENTIONING NICKEL.

Canada, Geol. Survey, Annual Report, 1898, vol. XI (N S.), pp. 123S-125S, 39S-41S.
Ibid, Annual Report, 1899, vol. XII (N.S.), pp. 37R, 38R; pp. 7, 8, 9. 87, 88S, 89S.
Ibid, Annual Report, 1900, vol XIII (N.S.), pp. 8S-11S, 99S-102S, 33R-36R, 26A.
Ibid, Annual Report, 1901, vol. XIV (N.S.), pp. 143A-147A, 8-10, 89, 90S, 56, 75J, 137A, 206A.
Ibid, Annual Report, 1902, vol. XV (N.S.), pp. 252A-269A, 443A-446A, 448A, 449A, 8, 9, 11, 13, 77S-80S.
Ibid, Annual Report, 1904, vol XVI (N.S.), XXIXA, pp. 7-11, 96S-98S.

Ontario,	First	Report	of the	Bureau	of Mines,	1891, pp. 88, 229-236.
"	Third	"	"	"	"	1893, pp. 182-191
"	Fourth	"	"	"	"	1894, pp. 20-24, 177-198.
"	Fifth	"	"	"	"	1895, pp. 18-20, 267-274.
"	Sixth	"	"	"	"	1896, pp. 40-46, 270-276.
"	Seventh	"	"	"	"	1897, pt. 1, pp. 93-97.
"	"	"	"	"	"	" pt. 3, pp. 230-232.
"	Eighth	"	"	"	"	1898, pt. 1, pp. 33-39, 106-120.
"	Tenth	"	"	"	"	1900, pp. 35-37.
"	Eleventh	"	"	"	"	1901, pp. 276-286.

FINIS.

ROYAL ONTARIO NICKEL COMMISSION

APPENDIX

TO THE

Report of

Royal Ontario Nickel Commission

Containing Minutes of Evidence,
Memoranda, Papers, etc.

PRINTED BY ORDER OF
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CONTENTS

PREFACE

The evidence of the witnesses who testified before the Commission, together with the more relevant portions of the written material submitted to it by various persons and companies connected with the industry, are herewith published as an Appendix to the Report of the Commission, which is contained in a separate volume.

Certain other information, oral and written, was obtained for the use of the Commissioners, which by reason of its confidential nature, or because of the limitations attached by the givers, they are not at liberty to print. Of all such information the Commissioners have been able to avail themselves in making their Report, while at the same time respecting the conditions under which it was received.

TORONTO, March, 1917.

Royal Ontario Nickel Commission

GEORGE T. HOLLOWAY, *Chairman*, WILLET G. MILLER, MCGREGOR YOUNG,
THOS. W. GIBSON, *Secretary*

SECTION A

EVOLUTION OF THE NICKEL INDUSTRY

Evidence of Mr. Frank L. Merry, Metallurgist, Swansea and Norway

(London, England, 24th March, 1916.)

CHAIRMAN: We shall be glad, Mr. Merry, to receive any information you may have to give us A. I understand you want to obtain information as to the connecting links in order to ascertain where the trade is at the present moment. The essential point really is that you wish the trade for the Empire, and you want to avoid pitfalls?

Q. Yes; and we want the benefit of your experience. In the first place, we want you to tell us how you became acquainted and connected with the Norwegian business—whether it was direct or whether it was gradually, through your connection with your other companies? A. It was gradually, from my grandfather's time originally, because we searched all over the world. Theophilus Merry went out to southeast Missouri, and the mine LaMotte was opened up and worked for the production of cobalt. Then we also worked in Spain, and opened mines there. Incidentally, I may say that my grandfather was captured by a brigand, and had to pay a ransom before he was released. This chief was to deliver the ore down the mountain side, and he delivered it regularly for a long period. I do not know what made them fall out afterwards, but they certainly did. Then we worked our way up to Norway, and purchased the Senjen mine at Krägero. We discovered nickel ore there. The works lasted about 35 or 40 years, until the price got so low that it no longer paid us.

Q. What price would nickel be then? A. It got down to about 8d. or 9d. a pound. That is the lowest price we ever sold nickel at. Prior to that it gradually fell. At the beginning of the fight with Rothschild and Le Nickel Company, nickel was selling at about 5 to 10 shillings a pound; then it gradually fell to 2 shillings, and from 2 shillings down to 10d., and then to 8d., and new people came in.

DR. MILLER: About what year would that be? A. It was in the late '80's. I have the prices here for 1896. It was when Sudbury got going that Thompson came in.

The OV and Saltcake Processes o Refining

CHAIRMAN: Which Thompson was that? A. It was Col. Thompson. He got a man named John Jenkins who told him about using salt cake. Thompson then applied it; he used salt cake for the separation of copper from the arsenides. He applied it to the sulphides ultimately —hence Thompson's process.

Q. That is probably when you were treating the Saxony ore? A. Yes—all arsenides at that period. It was the period of the wet process

Q. Which your people discovered? A. Yes, that is our own, away back. When we were dry-refining we used the OV process, for which there is a patent out.

Q. What does "OV" mean? A. The oil of vitriol process. We de-ferrated the matte, then put it through a 100-mesh and dissolved it with sulphuric acid. It forms sulphate of copper and nickel.

Q. Did you use strong or weak acid? A. Strong. We dilute it down a little. Sulphuretted hydrogen gas comes off, which you take off with exhaust fans. We syphon the liquor off into leaden pans and crystallize it out as sulphate. The mother liquor goes back; it will salt down; and a good deal of mother liquor is worked over again with a fresh lot. They pass the sulphate crystals through a hydro-extractor and just give them a wash and dry them, and then calcine in muffle furnaces at a high temperature. It requires a high temperature to decompose it. A very clean nickel is produced. Recovering the SO_3 in the chambers and using it over again, makes a very cheap process and a very clean nickel. All the platinum and all the precious metals are left in the sulphide of copper, which you recover by electrolysis.

Q. In the olden times you used to make an ordinary blister copper? A. Yes. That is the OV process. I see in the *Mining Journal* they have recently taken out a patent for that. It costs 1d. a pound from the matte to refine nickel.

Q. And for cobalt? A. For cobalt, more; that is another process entirely. You cannot very well dry-refine cobalt. You may do so, but there is much loss. I have done it. It makes three or four varieties—black oxide, the grey and the prepared.

Q. What would the "prepared" be? A. The ground prepared. Then you heat it to a high temperature in saggas. Then we also make cobalt in the same way as we do the nickel. We used to ship the oxide to the United States. I will show you where they killed us in the United States, and where our Government should have helped us. They take that oxide, grind

it fine, and mix it with tapioca and work it into cakes, cut the cakes into cubes and reduce them with saggas to the metallic state. The only sale we had for that was to Krupp's. There was a very small quantity of metallic cobalt sold at that period. Krupp wanted it specially for steel purposes.

Q. That is the cobalt? A. Yes.

DR. MILLER: How long ago would that be? A. Fifteen years.

Q. Who was using cobalt then? You say Krupp was? A. Yes for steel, and is using it now.

MR. GIBSON: Where were your works? A. Vivian's, Swansea. Our works originally were in Birmingham—my grandfather's place—and old John Vivian during my father's time persuaded him as a young man to go down to Swansea and put up nickel works there, with the intention of going into partnership with Henry Hussey Vivian. He became Sir Hussey Vivian, and then later, Lord Swansea.

DR. MILLER: You were speaking of the OV process? A. That is one of the best methods.

Q. From the matte to the refined nickel was how much a pound? A. 1d. a pound from the de-ferrated matte to the metallic nickel.

MR. GIBSON: How did you get rid of the iron? A. We blew it all off.

CHAIRMAN: A sort of converter arrangement? A. Yes. We used a Jumbo. I see that has been patented. We called it the Jumbo because we bought the furnace at the period when Jumbo the elephant went over to the United States. The tubes used to trumpet, and the consequence was the men named it "Jumbo" and the name has stuck to it.

MR. GIBSON: It was not because of the size of it? A. No. The action of the oxide of iron on the silica bricks ate them away rapidly. So we used a white magnesium brick. We had a lot of trouble.

CHAIRMAN: Was it a Grecian magnesite you used? A. Yes, quite white, and different from the Austrian stuff. That is the best, you know.

Q. The Austrian is the best? A. Yes, for that class of work. If you go to New Caledonia, you will see there magnificent deposits of magnesite. It is all taken up. It has never been worked.

MR. GIBSON: You say you sold cobalt to Krupp's at that time? A. Yes.

Q. What did they use it for? A. Steel. It makes an infinitely better steel than nickel.

Q. Did they use a large quantity? A. No. It was used specially for surgical instruments. I will tell you why they did not use a large quantity; it was because the price was too high at that period—about 7 shillings 6d. or 8 shillings or even 10 shillings 6d. a pound.

CHAIRMAN: Did they use it at all for high speed steel in those days? A. No.

Q. That is very recent, is it not? A. Yes.

Q. H. H. Vivian are the Birmingham people? A. The Birmingham house is a branch of our house. They make the tubes, the spoons, and that sort of thing.

Q. Are they directly connected with or taken up by the Anglo-French, now? A. No; that branch has separated off. All they do there is to make copper tubes and wire now.

Q. No smelting? A. No smelting at all.

Q. All the smelting that was formerly done by them is now done by the Anglo-French company? A. Yes; it is all done by the Anglo-French. I was going to show how they crushed us in the States. First of all, they put on an ad valorem duty. I have forgotten what it was at that period, but they kept on gradually increasing it. When they put on the first duty we competed favourably. Then they increased that duty, and ultimately it got to the point that we could no longer ship. That secured for them the whole of their home market. Then their increased output lessened their manufacturing costs, and then they dumped it down at cost into England. That is how they killed us. And they did the same thing with cobalt, cobalt oxide, until you fellows discovered the cobalt mines in Ontario. If you could work in conjunction with the French house you could do just what you like, and so you could with your nickel.

Treating the New Caledonian Ore

DR. MILLER: As to the cost of the nickel from the treated matte, the figure you mentioned is a very low cost; what would it cost up to that point? A. I can give you all those costs.

CHAIRMAN: That is mining, smelting and refining? A. Yes. The mining you have to take separately, because that will vary according to the class of ore you are going to treat, and also according to what are your sources of supply. With the New Caledonian ore the smelting will cost you 2d. a pound for the first matte produced, and the matte has 50 to 55 per cent. of nickel from a 7½ per cent. ore.

MR. GIBSON: This is not taking into account the cost of the ore? A. No. If that ore is a 5½ per cent. ore then those costs go up about a third higher than the 2d. a pound, and that bluff of the International saying they will take over New Caledonian ore and work to beat Canadian ore is not worth a snap of the fingers. Remember, the nickel produced is of excellent quality. There is no copper to separate; there is none whatever in the ore. But

[*F. L. Merry.*]

their first smelting costs are high, and you cannot Bessemerise it as you can the copper-nickel matte; it is a different thing. The moment it comes up to within 2 per cent. of iron there is a chill. If it contains copper, with the reaction of the copper you can blow off pretty nearly all the iron—within one-tenth—and you can take off that one-tenth afterwards.

CHAIRMAN: It is not merely a matter of the loss of nickel in the slag? A. That slag goes one stage back. Your loss is in your blast furnace. That is the main loss you have to watch.

Q. Suppose you had your converter temperature so intensely high that you could still prevent this chilling? A. You do not want it to get too high.

Q. Could not you carry it to the extent of getting down to 5 or 6 per cent. of sulphur in your matte whether there is or is not copper there, merely losing an excess of nickel in your slag which could be returned to the blast furnace? A. The whole charge will chill. But we blow it down to within about 1 per cent.

Q. One per cent. of iron? A. Yes.

Q. I was thinking more of getting rid of the sulphur. A. You have to have a little sulphur in order to enable you to blow it down.

Q. At present they are only reducing it to 20 per cent. of sulphur in the matte; supposing they reduced it to 5 per cent., what would happen apart from the heavy loss of nickel in your slag? A. It produces a very tough nickel.

Q. But you can run it to that point? A. Yes; but its nature is to chill.

Q. It would only mean using an excess of fuel? A. Yes.

Q. And returning a lot of slag? A. We make what is called a font. That is very hard to refine, because you have to bring it back to its matte form or you cannot handle it.

Q. How much sulphur would the font contain? A. From 2 to 3 per cent. It is really iron and nickel combined.

Q. I suppose that could be run into anodes for electrolytic treatment? A. Yes, it could, supposing your supply of electricity is cheap. That is absolutely essential. It takes from 6 to 8 horse power per kilogram of nickel. That is the consumption, and you can see it is pretty high. You can convert that into coal, and see what the cost is.

Refining Nickel in Norway

Q. What is the cost of current in Norway? A. In Norway the cost is very low, comparatively speaking—about 31 kroner per horse power year.

Q. Is that in Kristianssands? A. Yes. There are places where you could get it down to 29 kroner, but not now—not in these modern times. The tendency is to go up all the time.

Q. What would be the lowest price of actual production after you have got your plant up, and suppose you had no administrative cost or interest on capital to pay? What would it cost per horse power year simply to make your current and transmit it to the electrolytic mattes? Would it be as low as 10 kroner? A. No, not so low as that, because you have to pay interest on capital, and you have all your installations and everything else. The very minimum would be if you had your own water supply. Much depends on the cost of your installation.

Q. Suppose we ignore that, could not we say that the actual cost of making the current, irrespective of wear and tear or anything else, is so many kroner? What do you think would be the minimum? A. I cannot tell you that, because as a matter of fact the only cost is the interest on capital, wear and tear of machinery, and labour. Those costs are about 15 kroner. It depends on your sites. If you have to make big and expensive dams and miles of cuttings, you have to add the interest on that capital to your cost.

Q. I suppose about 20 kroner is the absolute lowest? A. Yes, about 20 kroner. One large user in the early days got some of his contracted for at 21 kroner. A new consumer goes to a municipality, and the municipality puts in the electrical installation. They are glad to get rid of their surplus power over and above the town's requirement, and they let him have it at a very low rate. He is a gainer, but he has brought the works there and the works have brought a population there, so that the town gains also.

DR. MILLER: The low price simply represents a bonus? A. Yes, that is what it is; but you can get it from 30 to 31 kroner per horse power year.

Q That is about $8? A. Yes. A kroner is 27 cents.

MR. GIBSON: To get back to the cost of this nickel, I understand it is 1d. from the matte that has been more or less treated— A. These smelting charges cost us 1d That was in 1896.

CHAIRMAN: Cupola smelting charges? A Yes Our de-ferrating charges cost us 2.3d.

Q. One penny for smelting, and how much for the other? A. A little over 1d. It is about 1.2d., the Jumbo smelting charges. You can take them roughly speaking at 1d. That is very high. No; it is .4d., I beg your pardon.

Costs of the Several Processes

DR. MILLER: What is the total cost—making the matte and treating it and refining it? A. That is the New Caledonia process The cupola smelting charges 2.43d ; then the Jumbo

[*F. L. Merry.*]

smelting charges .4d., but that is high, because the divisor was small. Calcining charges .4d.; washing and reducing .5d. That is 4¼d. There are sundry debt charges, that is the London office charges and that sort of thing. Those will diminish with your output. The output then was very small. Deduct the cost of nickel in the ore, 5d. The total was 1 shilling. The actual refining was included in the 4¼d.—that is smelting and refining. That is the N.C. process.

Q. It is about 8 cents more? A. Yes. The OV process comes to practically the same thing, about 11d.—nearly 1 shilling.

MR. YOUNG: That is based on actual operations? A. Yes.

Q. Taken for a period? A. Yes, taken every day. I keep my weekly returns, and at the end of the year the whole thing is done.

DR. MILLER: Those two processes are very close together? A. No; the OV is different altogether. With the N.C. process you would not recover your precious metal at all.

Q. I mean as to cost? A. Yes, almost the same. You get the copper. There are no copper charges there. That is actually on the nickel, and the copper is free. It is in favour of the OV charges.

Q. It runs roughly 1 shilling a pound? A. Yes. That is including general charges, too. It depends upon what your general charges are. That will depend on what the out-turn is. They should not amount to ½d., whereas it is 2½d. there.

Q. Those costs were the costs of the New Caledonia process, were they not? A. Yes.

MR. YOUNG: Where does the 1 shilling a pound put it? A. That puts it right into our warehouse. Then we have charges for commissions and packing. That will come out in our net price.

DR. MILLER: You referred to the fact that in one of those processes you would save the copper if it were in the ore? A. That is in the pyrrhotite ores. In the New Caledonian ores you have no copper. Although the two things are the same, the divisors are different, and much more amenable. You get less loss in slag from the pyrrhotite. From the New Caledonian ore you get very foul slags as a rule. On the average they run about ½ per cent. of nickel. If you get a 7½ per cent. ore you will only get 7 per cent. out. In 5½ per cent. ore, the same thing—the lower the percentage the higher the ratio of loss.

CHAIRMAN: You have got a constant loss regardless of the original contents? A. Yes, a constant loss, and that loss is a big item when you are paying 6d. a pound for it in the ore; and it is more now.

DR. MILLER: What year were those costs based on? A. 1897.

Q. And about what capacity would that represent? A. Well, about 7 tons a week. I do not know whether it was as high as that—more likely 5 or 6 tons a week. You see your costs will go down in proportion to your make and keep on going down, and so will your dead charges. Your mining costs and everything go down in the ratio of your output.

Q. I suppose the costs of the French Company, for instance, would be low? A. Very low indeed, but they have been awfully wasteful. They have thrown away millions, what with ore and slags at the beginning of it. Yet, notwithstanding those enormous losses, see how they pay! But they have not got any of those rich ores now. Prices will never go down as low as they have been. The Sudbury ores are not as rich as they were. We are not getting so much from the Sudbury ores as we were. New Caledonia is in the same position, if she wants rich ores now she has to go right into the interior; that means more cost for rail transit and more interest on capital. But she has millions of tons of 2 to 2½ per cent. stuff close to the shore.

Q. There is one point about the New Caledonia ore: that ore of 5 or 7 per cent. will not cost less? A. It will cost more. But the essential point is it will keep on costing more; the older it gets the more it costs, because the further afield you have to go. They are treating it on the spot, which is what I advocated years ago. I will send you down one of my reports on the New Caledonian ore. I reported on over 100 mines at that period.

Q. Those costs you have given at 1 shilling a pound—that is about 25 cents in our money? A. Yes. Thompson's process costs about 11d. I know every item of the charges. Our charges are a little less than his.

Q. The cost of his process was about 11d.? A. Yes, but his cost for ore was less than it was with us; therefore he got an advantage in that way. Then he got better prices in the United States, which was half the world's market at that period. Then he dumped it on us. I sold nickel at 8d., which was below cost price, in order to keep our customers together. I opened up an agency personally with China and Japan and then Russia—right through there.

Q. If it were costing you 1 shilling a pound on that smaller scale, I suppose the large French Company, working on a larger scale, might produce it for 10d. or something like that? A. About 10d.

Q. About 20 cents a pound? A. Yes. Those costs can be lessened now with improved processes and apparatus, right down very nearly ¾d. Your prices are good now; they are excellent, and I never expect to see them down to 1 shilling 1d. again. I calculate everything above 11d. is sheer profit.

Q. Twenty-two cents? A. Yes.

[*F. L. Merry.*]

Ores from Other Lands

CHAIRMAN: You were telling us about the Grecian ore: do you know anything about the Tasmanian ore, that very rich stuff? A. Yes. I got 200 tons from Tasmania originally.

Q. That would be over 10 per cent.? A. It goes about 11 to 13 per cent., with about 8 to 10 per cent. copper. It is a pyrrhotite.

Q. Do you know what the place is called? A. Yes.

Q. Is it in the Zeehan district? A. Yes. I can show it to you on the map. It is on the south portion of the island—south and west. It is on the south coast that you find it. The port is Trial Harbour.

DR. MILLER: Would that ore have precious metals too? A. Yes. I will tell you another curious thing about the pyrrhotite. You will find your platinum is more associated with chalcopyrite. That is more the case in Norway than it is with you. Where you find your chalcopyrite, you will find very little of the platinum in the nickel ore itself. With nearly all nickel ores, even with our wet process, we used to recover it, because there is one portion of the dissolving tanks where it accumulates. It will collect there. When it got rich enough we refined it. But it does not matter what portion of the world it comes from, you would always get those precious metals.

CHAIRMAN: But practically none in New Caledonia? A. Yes, a little.

Q. You would expect it, but I did not know you got it in the oxidized ores? A. Yes, but they cannot recover that. There is not nearly as much as you have in your Sudbury ores or Norwegian ores.

Q. Nor in the Tasmanian? A. In the Tasmanian, yes, there is a little.

Q. But not in the oxidized ores? A. Not in New Caledonia.

Q. It is practically negligible? A. You can say it is there, and that is all—traces of it.

Q. As regards palladium, do you find there is more of that and platinum in the Norwegian than in the Tasmanian? A. Yes.

DR. MILLER: You have referred to Sudbury, New Caledonia and Norway; I understand you say that these other countries cannot stand against Sudbury? A. No, they cannot.

MR. YOUNG: Could we not have the reasons given, shortly? A. The smelting charges are easier. They have both copper and nickel, whereas in New Caledonia the smelting is very much harder. The first smelting is harder; the refining is easier afterwards. But the costs are greater, and the losses in refining in the New Caledonian ores are greater than in the case of Sudbury.

DR. MILLER: The losses are greater by reason of the method which they are using? A. More from the character of the ore. It is silicate of magnesium; as a matter of fact it is a decomposed soapstone, whereas the Sudbury ore is a good fusible ore.

Q. If we in Canada were selling nickel at 25 cents a pound, the other people would have hard work to compete? A. Yes, it would be crushing them It would be an awfully foolish thing to do. You would secure the trade, but it would be foolish. You would encourage the steel people, but there would be nothing gained by it

German Interests in Norway

CHAIRMAN: Because, presumably, they have got to use it at anything like a reasonable price: they cannot do without it? A. That is so. I would not cut it down so fine as that. You could cut it down to 1 shilling 2d. or 1 shilling 3d and you would kill Kristianssands if you did that. There is another thing. Germany will take all the Kristianssands nickel at whatever price. They will finance them. That will be their leaning post; because that is the only external source of supply Germany can possibly have now. Germany's output internally is, all told, about 2,000 tons per year only That is from all sources in Germany itself. She has no more except what she imports.

MR. GIBSON: She gets about 1,000 tons from Norway? A. Yes

Q. That makes 3,000 tons altogether? A. Yes.

CHAIRMAN: Do you know anything about the cobalt in the ore from South Africa? A. No.

Q. There is a lot of blister copper containing cobalt and nickel which goes over from there to Germany? A. I think there is.

DR. MILLER: Continuing the previous point, I understood you to say that the Germans are practically financing the Norwegians? A. Yes.

Q. I think I understood you to say that the Germans were also interested in the International? A. Yes, but that we cannot prove.

MR. YOUNG: In what way? Are the Germans shareholders? A. Yes, shareholders, and probably on the directorate. Thompson himself went over to Paris when he fell out with Mond. He tried to stop Mond refining. He knows Paris very well, and he made an agreement with Le Nickel Company. The majority of the shares of Le Nickel Company were bought by the Metallgesellschaft. The Metallgesellschaft's money put up that big transport at Lyons, and they acquired shares in the market and secured the control. Then the bulk of the shares of Henry R. Merton are held by the Metallgesellschaft and that other German metal bank.

[*F. L. Merry.*]

Q. And Beer Sondheimer? A. Yes, and Aaron Hirsch. The Metallgesellschaft is at the back of these firms; at the back of the German banks is the German government, and in order to capture the trade they will spend what money they need.

DR. MILLER: Do you think at the present time most of the shares of Le Nickel are held by the Germans? A. I do not know since the war, but they were prior to the war.

Q. If the Germans were in control of Le Nickel Company before the war, and if they hold large interests in other companies they will probably be the same German crowd? A. Yes. It is really the Saxon government. Kristianssands is the same thing; they have it in their grip. Just as this war broke out they sent over the necessary cash to continue.

CHAIRMAN: That is to Kristianssands? A. Yes.

DR. MILLER: If the Germans control these companies, would it not be a proper subject for investigation by the French government? A. Without a question—without doubt it is.

MR. YOUNG: I suppose a good deal of that which you have been saying now is mere conjecture on your part? It is only what you think—a well-founded suspicion? A. No—actual contact. I have run against them.

Q. Actual contact with individuals or interests? A. With interests, and I ran right against them.

CHAIRMAN: Personal experience? A. Personal experience of those things. I could tell you a lot more, only I have not time. But I want to fight it pretty well.

Q. You evidently do. A. I have been fighting it. I fought it for ten solid years before, and it crippled us.

MR. YOUNG: Did you ever make any sort of remonstrance to the government or anybody else- A. Yes, and they took no more notice than a snap of the fingers. Of course the German government helps every industry. That is part of their system. They send their students abroad; they take any position they like at any price, but the German government subsidizes them. The Norwegians do exactly the same thing.

Q. Have you any copies of the correspondence between you and the officials of the government here, or any other government? A. No; I could not lay hands on that. It is only now that they have commenced to open their eyes. In the early years you could never get the government to help you in anything of that sort. We tried to get duties imposed, and you know what that is.

Norwegian Mines and Smelters

CHAIRMAN: Could you give us the names of the mines and smelteries now working in Norway? A. Yes. They are the Senjen, Evje, Ringerike, Dambler, Krägero, Evans's old mine, which was recently opened up; it has not been worked for fifty years. Nearly all those other mines are controlled by the Kristianssands people, except Dambler, which is worked by Johan Dahl. That is only recently. There is a smeltery there.

DR. MILLER: There are two smelteries? A. Yes. It has only recently reopened.

CHAIRMAN: That is an independent concern? A. Yes. I believe the English are at the back of that.

Q. Who do you think will get the matte from the new smelter? A. It will not go to Germany. It will probably come either to Swansea or to Wiggin.

Q. Will that be in opposition to Hybinette's people? A. They are really Beer Sondheimer.

DR. MILLER: What do you think the ores average in nickel on the whole? A. About 1½ per cent. of nickel as it goes through. If you select right you will get more, but you lose a lot.

Q. How much in copper? A. About half the nickel.

CHAIRMAN: As much copper as nickel? A. It is about two-thirds nickel and one-third copper, or a little higher ratio of copper than that.

DR. MILLER: What do you think it would cost per ton of ore to put out the ore, roughly? A. About 6 shillings a ton. It depends on the mine. On an average, call it 6 shillings a ton. With some it costs 4 shillings 6d. and some it is as high as 10 shillings. They mine pretty cheaply; the labour is cheap out there. Formerly they did not have air compressors, but now they are putting them in.

CHAIRMAN: Does that mean bringing it to grass? A. It brings it right to the furnace, because it is right alongside.

MR. GIBSON: Do they roast the ore? A. Not now. They used to. They take it on to matte and convert it. I doubt whether they can do it now so well. At that time the Tasmania ore had 13 per cent. of nickel and from 8 to 12 per cent. of copper. They ran their matte up to about 20 or 30 per cent. But now they cannot get that stuff, and they cannot get the Greek ore; they have only what they had in stock. And their costs will go up consequently.

DR. MILLER: When they were using these outside ores—? A. It increased the quality of their matte. The matte which should have been 9 per cent. really went up to 12 or 15 per cent.

Q. You said they were just putting in air compressors at the mine? A. Yes, at Ringerike; they are putting in the foundations for air compressors there—about 160 or 180 feet maximum depth. It is opened up at various levels. They have been doing a great deal of drilling there. It is very good ore. In one direction it goes underneath the marsh, but they have not got it yet. I know it from early days. We sunk a shaft. That ore used to go 3½

[*F. L. Merry.*]

per cent. nickel on the average. Ringerike, I think, yields a little more platinum and precious metals.

Q. Does it cost 30 cents a pound? A. The refining?

Q. The whole cost? A. The cost would be about 1 shilling 1d. or 1 shilling 2d. a pound. They had a contract with Beer Sondheimer. The original contract was 2 kroner 55 per kilo.

Q. Does that mean 2.55 kroner? A. Yes, that is 2 kroner 55 ore per kilo. That would equal about 1 shilling 3d. or 1 shilling 4d. a pound. They were selling it at that price.

MR. GIBSON: Do you know what price they are getting now? A. No, I could not tell you now in these war times. I know it has increased. The copper they sell on the basis of the London quotations. The price of nickel in Germany is 13 shillings a pound, but I doubt whether Kristianssands gets that. The probability is that Kristianssands gets 4 or 5 shillings a pound; but that is a guess. I know what the old contract was.

Q. Six shillings roughly, we heard. A. Yes, but that is not going to last for ever. As soon as the war is over it will drop.

Early Competition in Selling Nickel

MR. YOUNG: Your first opposition from the American concern, the International Nickel Company, was at the time of their putting on that ad valorem duty? A. Yes, Thompson; and then we were both weak, Le Nickel Company and ourselves from our own fighting. Thompson dumped it on us at 8d. or 9d. a pound at that period.

Q. Do you remember how long ago that was? A. I can give you the exact date. It was before we took up the Murray. It made us come over for Murray.

Q. We can fix that date? A. Yes. It was the Canadian Copper Company at that period. There was a lot of copper they did not know what to do with, and they got our man, John Jenkins, over there and they started dry-refining with salt-cake. You can get the exact date of that.

DR. MILLER: They afterwards got Hybinette? A. Yes; he had been in southeast Missouri, and drifting all round the place.

Q. He had had experience over here in Europe? A. I do not know where he got it. My brother knows more about him than I do.

MR. YOUNG: When you got interested in the New Caledonia properties you had opposition from the French Company? A. Yes, and no end of trouble.

DR. MILLER: Do you know anything about these competitors of theirs? A. The best ore is on the west coast, the chocolate ore. The original discovery was made on the east coast; that is the garnierite. Those mines were right alongside the water on the east coast.

Q. Do you know anything about the company which started in competition with Le Nickel in late years, which now has a small refinery in the United States? There is one company which has a small refinery there? A. I suppose there are several small ones now.

Q. This is on the New Caledonia ore.

CHAIRMAN: It comes from Ballande? A. That is only one of the strings. Ballande bought the Antwerp refinery; he handled nearly all the ore out there.

DR. MILLER: Why is he competing? A. I do not know. Is he in with the International now?

DR. MILLER: He has a refinery of his own in the United States? A. Does he get any opposition, any trouble from the International?

CHAIRMAN: Apparently he has been able to fight it? A. Yes, and fight it easily, I expect.

Q. Apparently; and that was the case even before the war; so it looks as though he has been able to deal very successfully with the New Caledonian ore? A. Ballande is a little king there at the present moment. He is a pretty wealthy man now, but he was fighting very much with Le Nickel Company.

MR. YOUNG: There is one question I should like you to pursue; that is with regard to the relative costs and advantages of refining in the United States, Canada, Wales, Birmingham and Kirkintilloch? A. I think that has been covered.

CHAIRMAN: I think you were going to develop that—the question of freight and so on? A. On the coast in Canada you can absolutely compete with any one of them.

Q. If it comes to the electrolytic process? A. Then you have to go to your power.

Q. There is no necessity to be on the coast then? A. No.

Q. Because you have no difficulty with the by-products? A. No. You do not use much fuel after the converting.

Q. And very little chemicals. Sulphuric acid is about the only thing, I presume? A. Yes, and a little hydrochloric acid—very little, though.

Q. Do they produce any nickel salts or nickel oxide in Norway and sell it as such? A. Very little. They make a little sulphate. There is not much demand for it. It is just a little local thing. You can always make a little sulphate of nickel.

Q. Within limits there is a growing demand for that? A. Yes. There is only a limited market for electro-plating.

[*F. L. Merry.*]

Where Nickel is Now Being Refined

Q. At how many places are they refining nickel in Great Britain now? A. There is Mond, the Anglo-French, Henry Wiggin and Company, Birmingham, and Erdington and Kirkintilloch.

Q. Erdington and Kirkintilloch are both Le Nickel? A. Yes.

DR. MILLER: How many refiners are there in France? A. There is Havre.

Q. That is Le Nickel? A. Yes. That is the only one I know of.

Q. Before the war there was a smelter in Belgium, but no refinery, I suppose? A. Yes.

CHAIRMAN: The matte all went to New Jersey, I am told? A. That matte was sold. Part of it used to go through the same German agent; part went to Le Nickel Company, and part went to Beer Sondheimer and Kristianssands. You see the link there. I used to divide the parcels.

Q. I understand that a good deal of Ballande's went to New Jersey—that he brought it as 45 per cent. matte from New Caledonia, smelted it up to 75 per cent. at Antwerp, and sent a good deal of it—the bulk of it I thought—to New Jersey, to the United States Nickel Company? A. Very likely. Is that Joseph Wharton's old place?

DR. MILLER: No, I do not think so. A He sold it to the International Wharton had electro-deposited nickel. I think that is where he got his experience. Then there was Fleitmann; he used to be in Germany There are several refiners there. There was the Saxon Government and Maletra.

Q. Outside of those three countries and Norway there are no other refiners, I suppose? A. No. There is Le Nickel and the International and Mond, of course. The Mond process is the only process which is a fairly excellent one. It is very cheap to manipulate.

The Cobalt Refining Business

CHAIRMAN: You have certainly given us a great deal to think about? A. I should like to get into cobalt—there must be money in that at the present moment.

Q. It is in good hands in Canada, I believe? A. There will be an awful waste there, and it is a very easy proposition.

Q. Of course it is ideal stuff for the process which your grandfather used? A. Yes. You can cheapen it a lot.

Q. As a matter of fact, the process they use now for treating the cobalt ore is practically no different from the process that was used fifty years ago? A. There are lots of ways of cheapening that process.

Q. They get very good oxide—72 per cent.—2 per cent. better than the old German and English standards? The Germans refused to have it because they said it was not good enough. A. The Cobalt Association divided it among them in the ratio of sales; the public auditor used to audit the books every six months, and your ratio would be divided off in proportion to what you sold the previous six months. If you sold more than your proportion, you had to pay the difference to the others; if less, you received, either in cobalt or in cash, optionally. It was generally better to sell as much as you could and pay the fine—I found that out at the beginning—because it gave me a bigger proportion of the market.

Q. Did you ever supply any cobalt—I asked you this before as regards olden times, but now I am asking about recent times—to those people who make the iridium steel, as they call it, which is merely a cobalt steel containing tungsten? A. I do not remember it. The only people we sold it to were Krupp's We used to ship to the United States to overcome the ad valorem duty. The marketable stuff is oxide of cobalt. We used to reduce it to the metallic state and send it to the United States and re-burn it to oxide. You can take the black and reduce it to the metallic state and it will burn back to black; and you can take the prepared and reduce it to the metallic state and it will go back to prepared. Then they put on an ad valorem duty on all products containing cobalt, and that stopped us. In nickel we made cubes, shots, rondelles, plates and grain.

Q. Do you make shotted? A. Yes. Shotted is a little bit more.

Q. In the States they do a lot of that? A. Yes.

Q. What would the grain be? A. Instead of being in cubes the grain is simply of irregular shapes.

Q. It is similar to the cubes, only irregular? A. Yes. We dry it in these cakes and it passes through a special mill, which simply cracks it. We take these and reduce them to the metallic state.

Q. They are merely irregular in shape, but are of the same composition? A. Yes. Vickers Maxim used to take that in preference to the cubes. The Chinese and Russians like the cubes.

Q. And there are some people who even insist on the cubes being polished? A. Yes. We sent the Chinese 99.8 per cent. stuff, and I have heard them complain of it because it was hard to melt. Another firm was sending them over beautiful coloured cubes, with 3 per cent. of copper. I told them I could let them have the same material with pleasure; and I did. If it contains a little copper it is much easier to make the cubes.

Q. Of course all you have to do is to put it in a machine and roll it about for a couple of hours, and you have the polished stuff? A. They do not crack so much in the drying. There is quite an art in making cubes—making them with an even face and without cracking. The nickel is no worse in quality if that is not done; it simply does not look so well, that is all.

[*F. L. Merry.*]

Special Meetings of the Commission

A special series of meetings was held by the Commission, after due advertisement in the local newspapers, at Sudbury, Cobalt and Timmins, on the 25th and 28th September, and 2nd October, 1916, respectively.

In the first-named town, which is the centre of the nickel area and lends the name by which the district is commonly known, it was natural to find a keen interest in the nickel industry and in everything pertaining to its welfare. The Commissioners are indebted to the Sudbury Board of Trade, and particularly its president, Mr. P. Gorman, for arranging for the attendance of representative witnesses acquainted with varying aspects of the industry; but, as in the other two places, an opportunity was afforded to any one who wished to do so, to make representations to the Commission on any branch of the inquiry.

The question of taxation of mines was discussed at some length at Sudbury, and this was the principal topic at Cobalt, the centre of the silver production, and Timmins, the leading town in the gold mining area of Porcupine, where, as was to be expected, the chief metals of local production take the place of nickel in the public interest.

At Sudbury, and to a smaller degree at Cobalt, information was obtained regarding the extent of the nickel ore reserves, and the probability of enlarging the same by further exploration.

Representations were also made by witnesses as to the refining of nickel and the desirability, from business and patriotic motives, of establishing this industry within the bounds of the Province of Ontario, or at any rate within the British Empire.

The evidence given by the witnesses has been divided and grouped under two headings, according to the subject matter of the testimony, namely, in Section B, Nickel Ore Reserves and Nickel Refining in Ontario, and Section N, Taxation of Mines. This arrangement, adopted for the sake of clearness and convenience of reference, explains what in a few instances has the appearance of abruptness in the method of questioning or in the testimony of witnesses.

SECTION B

NICKEL ORE RESERVES AND NICKEL REFINING IN ONTARIO

EVIDENCE AT SUDBURY, 25TH SEPTEMBER, 1916

Mr. Thomas Travers, Diamond Drill Contractor, Mayor of Sudbury

CHAIRMAN: What has been the extent of your experience in the nickel district, Mr. Travers? A. I came in here with the Drury Nickel Company, operating in the township of Drury, and was superintendent of their work during the period of their operation. After that, I was Canadian agent of the American Nickel Company—Mr. Joseph Wharton's company—at the time the International Nickel Company was formed. His holdings went to the International Nickel Company, and I went over to the Lake Superior Power Company. I was superintendent of nickel mines during their period of mining, seven years; and then I went to the Canadian Copper Company as assistant general superintendent in the mining department at Copper Cliff. I left them and went contracting. I have been contracting now for the last eight years.

Q. On what points do you think, Mr. Travers, you can help us most? A. I think I can help you most by describing the ore bodies that have been discovered.

Q. It would be better if you were to give your experience in your own words than in reply to a series of questions from us, if it is possible? A. I don't think my experience with the companies I was with would be of much use to you. I have built smelters and opened up different mines and all that, but I don't think it would be of any use in this enquiry.

Q. The main thing, of course, is the present position and the prospects? A. During my time of contracting I have been working in the Cobalt camp, Porcupine and Sudbury, and I may say all through Canada, clear from Quebec to Edmonton; mainly in developing ore bodies, the most important of which have been in the nickel district. We have developed some very big ore bodies in the nickel district. Amongst them were the Whistle mine, W.D. 16, and the property adjoining Nickel lake, all on the north range.

MR. GIBSON: Do you remember the location of Nickel lake? A. I think it is W.D. 152. There are several properties there; also the Falconbridge property, on the eastern range; the Murray mine; the Elsie Mine; Gertrude mine and Mount Nickel on the south range; and the Levack property on the north range. We are now developing the Blezard mine on the south range. On all these properties we located ore bodies with the exception of the Blezard mine. We have not made any discovery there yet. We blocked out large ore bodies by diamond drilling.

CHAIRMAN: Then, the result of your diamond drilling experience has been that, roughly speaking, where you have drilled you have found good ore bodies? A. Not in all places. We have drilled in places where in a small amount of drilling we didn't find ore. But in properties where there were any good reasonable surface appearances, and we drilled them thoroughly, we have got big ore bodies.

Tonnage of Proven Ore in Sudbury

Q. Have you any idea as to the present quantity of proved nickel ore in Ontario, or in the Sudbury district? A. A member of the Dominions Royal Commission that was here a few days ago asked me that question. and I told him about seventy million tons; but on thinking it over very carefully, I should say there is between sixty and seventy million tons. There is at least sixty million tons of ore developed by diamond drilling in the Sudbury district.

Q. That is what we should call proven ore? A. That is proven ore. If you take a map of the district you will see there is something over one hundred and thirty miles of nickel-bearing contact following the rim of the nickel district around, and the off-shoots from it, and of that there have probably been ten miles developed; the rest of it is undeveloped.

Q. What would you consider as a basis for your estimate? A. None of those properties I have mentioned to you as developed have less than 300,000 tons of ore.

Q. And the amount of nickel and copper: the assay value? A. The lowest of them would average three per cent.

Q. Is that all nickel or nickel-copper? A. I mean the combined metallics.

MR. YOUNG: About two to one? A. Yes, they would run from that to—some of them—six per cent.

Q. You said something about having really only developed ten miles out of the entire nickel contact; what is its full length? A. About one hundred and thirty miles; something over one hundred miles of contact.

Q. And what are the reasonable prospects for the balance of the district that has not yet been developed? A. The best surface showings have been developed.

Q. The best of them? A. Yes; but I believe there are going to be big ore bodies discovered where the surface showings are probably not so good as those that have been developed.

Q. How do you form your opinion? A. For instance, Levack No. 1, the surface showing on that is very, very small, yet the development work there so far has shown up in the neighbourhood of six million tons of ore, and the property is not fully developed. More work would have shown up more ore.

Q. Now, on what do you base that opinion—on your own experience? A. On my experience in the district, from contacts I have worked on. The ore in all cases here lies between the norite and the greenstone or granite. Sometimes the greenstone is between the ore and the granite, but the ore lies underneath the norite. It may lie on the granite, but generally on the greenstone: so I think where you get the contact between the norite and the greenstone and the granite close by, there is a prospect of paying ore.

Q. That is your experience? A. Yes.

Q. Are you familiar with the literature on the district? You have looked into the geological conditions? A. Yes. In fact, I have conversed with Dr. Coleman and Mr. Knight and Mr. Hitchcock, who has gone to the Canadian Copper Company. I have had a good deal to do with them in a good many ways, and get a good deal of information from them.

Q. The extent of those deposits would, of course, be conjectural? A. Yes. I am only speaking, in the good mines, of what has been developed.

Q. But you think there is a reasonable expectation of adding large deposits in the future as they develop, along the lines you have described? A. Yes.

MR. GIBSON: What would, in your opinion, be the most feasible methods of ascertaining where these deposits exist? How can you tell from the surface? A. Just from the geology of the country. No ore has been discovered in the district where there was no contact.

Q. But do you think every point on the contact is a favourable spot? A. No, I don't think it is, because even where there is a big surface showing, you come to the end of the ore at both sides. The ore pinches out; the contact closes. Now, there is no reason why, in my mind, it would not open out at other places in the same way.

Q. And some of these other places would be covered by drift? A. Yes.

Q Do you think that magnetic readings are of assistance in locating these underground bodies? A. Yes. Where they are covered with drift, the magnetic readings are of much assistance in locating the direction.

Q. Might you get the magnetic readings where diamond drilling would fail to locate a body of ore? A. My experience has been that where you get a high reading you never get a large ore body. Where you get low uniform readings over a large district, you get the large ore bodies.

Q. Would that be due to the somewhat feeble magnetic action of pyrrhotite? A. I would judge so.

Q. Have you known bodies of ore to be located by magnetic readings where, on the surface, there were no showings? A. Well, up at Levack, when I was working there, Mr. Demorest made a magnetic survey of the property, and the readings extended over such a large area that we simply left it; we didn't think there was anything in it; but after we started developing the property it all came back to me—this survey that Mr. Demorest had made—and the ore was right exactly where the readings indicated it.

MR. YOUNG: That confirms your own statement that you have given us here? A. Yes.

Prospect of Discovering New Ore Bodies

MR. GIBSON: Where are you likely to get these unknown deposits? A. Well, I could not very well say that. All the large ore bodies have been found between the contact of the norite and the greenstone, dipping on the south range to the north, and on the north range to the south, at an angle generally of forty or forty-five degrees, and our experience has been when we get away out from the outcrop twelve or fourteen hundred feet, they will commence to flatten again, say to 35 degrees instead of 45 from the horizontal.

MR. YOUNG: Now, is there anything you would like to add from your experience, to the information contained in the reports of Barlow and Coleman? A. My opinion is that it is clear enough in these reports.

Q. Have you found the reports of the geologists and mineralogists of much assistance in your practical work? A. Yes. Dr. Coleman's report especially is of very great assistance. You can rely on it right along. I go by it always, and since it has been revised it is much better.

Q. The working out of the geology in the district has been of much assistance to the practical development of the ore? A. Yes, it has been of great assistance.

[*T. Travers*]

MR. GIBSON: Would you advise diamond drilling in the hope of developing underground deposits notwithstanding large quantities of drift on the surface? A. Yes. If you are sure the contact is there.

Q. Have any instances come to your notice of ore bodies having been located at haphazard? A. Yes. There is a gentleman on the committee who will be able to tell you more about it than I could. There was a deposit of that kind discovered here in the last year. I have great confidence that there will be all kinds of ore developed in this district.

Q. Have you ever made any estimate of the quantity of ore, or can such an estimate be made, on properties which are not owned by the large operating companies? A. No. No ore has been proved up by anybody else except at one mine, the Mount Nickel mine. That is the only mine not owned by those companies that has been proved by diamond drilling.

Q. Do you think there is a possibility of considerable ore being found on the properties outside of these companies? A. Yes.

Q. On which range, mostly, would that ore be situated? A. I think it would be proved on the north range.

Q. You speak of the north range as extending from the Falconbridge up to the Whistle and west and southwest to the Sultana? A. No, the Sultana is on the south range.

Q. Well, the Trillabelle? A. That is on the south range too.

Q. What would you call the western end of the north range? A. The end, so far as I am concerned, is Levack.

Q. Do you think that there is a continuous rim or basic edge of norite? A. I think so.

Q. As Coleman shows it on his map? A Yes.

Q. Although in places it may be covered by drift and in places by barren rock? A. Yes, but you can find the contact all around that rim, as it is shown on that map, and in a great many places you find gossan, but not very much clean ore. There may be little bunches of clean ore; enough to indicate that ore bodies exist there.

Q. Do you ever find bodies of pyrrhotite that are not nickel-bearing, in this neighbourhood? A. No, not at all.

Q. Pyrrhotite means nickel? A. Yes.

MR. YOUNG: Do you think the metal contents are about as you have given us in the whole district; about three per cent.? A. Oh, the average would be more than that. I say the lowest would be about three per cent. I should judge the average would go over four per cent in the whole district.

MR. GIBSON: Does the ore on the northern range carry more or less nickel than on the southern range? A. It carries a little less.

Q. What about copper? A. Copper would be about the same.

Q. As much copper on the northern as on the southern? A. Yes. I think the copper on the northern range runs a little higher. In the south the ore runs over two nickel to one copper, but the nickel contents are a little lower in the north range than in the south range.

CHAIRMAN: Do you find the country rock adjoining the actual ore bodies, richer in copper relatively than the ore body itself? A. Yes. Next the hanging wall you find more copper, as a rule.

Q. In other words, the more silicious rock would probably be richer in copper relatively to the nickel? A. Yes. In the low grade ores of the district, that is, the ore mixed with rock, there is more copper than nickel.

Q. Is there anything else you would care to add? A. As regards the refining of nickel, like all other people in the district, I would like to see it refined here, but I am not well enough posted to know the conditions.

Mr. J. F. Black, Mine Owner, Sudbury

CHAIRMAN: Mr. Black, perhaps you will give us in the way Mr. Travers did, a little statement as to your connection with the nickel industry, and then your views in your own language, and allow us to ask questions? A. I have been nineteen years in the district. I came up here on behalf of a syndicate in Montreal, and started in to develop a copper and gold property back at Markstay, known as the Mount Etna mine. I was there two years, and while there I got interested in the Sudbury nickel district. The first property I was interested in was in the township of Trill; it was afterwards sold to the Great Lakes Copper Company. Then I became interested in the Mount Nickel property and in Levack. I have done considerable surface work during the last eighteen or nineteen years, but no deep mining. I have studied the geology of the district, and have been in close touch with both the late Dr. Barlow, who was a near personal friend, and with Dr. Coleman. I have read and studied carefully all the literature that has been published on the nickel industry, both by the Dominion and Ontario governments; and have kept in touch in other ways with the development of the district. I have owned several nickel properties. I can say that I agree with all that Mr. Travers has said, as far as he has gone.

Q. Does that refer to the prospects, the amount of developed ore and the prospects of further development? A. I could not speak as to the amount of developed ore except what I have learned from others. I have had no personal experience in the development of ore by diamond drilling, except in one or two cases where I have done diamond drilling myself, but only in a small way. Mr. Travers has made a business of diamond drilling. He can speak better than I.

MR. YOUNG: Did you find the literature useful and reliable? A. Yes, in most cases very reliable.

Q. And you think a layman like myself would be justified in relying upon it as a foundation for deductions? A. To a large extent, yes. Of course, there are matters in which later investigation or later development might lead to some different result. Those reports have been very helpful, in my opinion.

CHAIRMAN: Have you heard of any promising properties being found by ordinary prospectors with no experience whatever? A. Yes, I think the history of the district proves that most of the valuable mines of to-day have been found by prospectors, men without any technical knowledge.

Q. But during, say, the last few years, have you heard of any promising properties located in any way, outside of those that are previously well in? A. Yes; there have been properties located within the last ten years by ordinary prospectors in this district.

MR. YOUNG: You said you were on record already, Mr. Black; where, officially? A. Well, both at meetings of the Sudbury Board of Trade which have been held in this room during the last two years, and at a meeting of the Ontario Associated Boards of Trade, held in Toronto in February, 1915. There was a resolution passed at that time in favour of refining nickel in Canada.[1]

Q. That is not so much dealing with the matter of taxation as with the refining? A. No. But in dealing with that subject, the matter of taxation came up.

Q. I made a note here that you were on record, or your views, with respect to the taxation, and I have in mind getting a statement from you or a memorandum? A. I can give it to you if you wish.

Q. Is there anything more that you would like to say upon these matters? A. I have nothing more except to say that I am very strongly in favour of nickel being refined in Canada. I don't think we have the right to say where it shall be refined, but I think that our nickel should be refined and controlled within the British Empire. The history of the last two years should impress that very strongly on our minds.

Q. Do you draw a distinction between Ontario and Canada? A. No. Of course, I would be in favour, first of all, of it being refined here.

Q. I mean the refinement anywhere in Canada would meet your wishes? A. Yes, I think so.

Q. Or within the Empire? A. Yes; I think it should be within the borders of Canada, and away from the border. We are very good friends with the Americans to-day, but we do not know the day that something may happen, and I think we should take all necessary precautions and any refining or munition plants should be away from the boundary.

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[1] The resolution passed by the Sudbury Board of Trade at a meeting held in the council chamber December 24th, 1914, was as follows.—

"That the Sudbury Board of Trade accept and believe the statement of the Canadian Government, that with regard to the export of nickel matte from Canada to the United States, the Canadian Government and Imperial Government are entirely satisfied with the precautions that have been taken to prevent the export of refined nickel to Germany, and we are not aware of any facts, nor have we any reason for believing that the product of Canadian nickel matte is reaching Germany via the United States or any other neutral country, since the commencement of the war:

"That this Board of Trade realizes the importance of the nickel industry in the Sudbury nickel area, carried on by the Canadian Copper Company and Mond Nickel Company, and is of the opinion that no action should be taken by the Government by placing an export duty on nickel matte or prohibiting the export of nickel matte, without making a thorough investigation of the matter, as the Board of Trade and this community do not wish large industries such as the Canadian Copper Company and Mond Nickel Company jeopardized by misguided patriotism, or rival interests."

The resolution adopted by the Ontario Associated Boards of Trade at a meeting held in Toronto 25th and 26th February, 1915, was as follows:—

"Whereas we believe the people of Ontario as a whole desire the assurance that, should any future occasion arise, the nickel produced in the Dominion of Canada, in so far as the refined product goes, should be under the control of the Government.

"And whereas the Honourable the Minister of Lands, Forests and Mines has announced that it is the intention of the Government to appoint a Royal Commission.

"Resolved, that the Ontario Associated Boards of Trade assembled, highly commend their action, and we, as a body, sincerely trust the men appointed will be non-political, practical, and thoroughly impartial

"And be it further resolved that it is in the interests of the Dominion of Canada and the British Empire that the refining of all nickel and copper matte be under Government control and be refined in Canada."

[*J. F. Black.*]

Mr. W. E. Smith, Mining Prospector, Sudbury

MR. GIBSON: Have you been prospecting for nickel? A. Yes, but not to a large extent. Not so much as for iron and other ores.

Q. Do you agree with Mr. Travers that there is a strong probability of undiscovered ore bodies on the nickel range? A. Yes, I do.

Q. Have you any means of telling how they might be discovered? A. Well, my experience is that except where the ore exists at the grass roots, the only way you can locate them now is by sinking or drifting or diamond drilling, whichever would be preferable.

Q. What would you suggest as the best method of ascertaining where the diamond drilling should be done? A. I think the geological work that has been done by Dr. Coleman in locating the nickel contact has been invaluable in that respect.

Q. Would you think a haphazard system of drilling wherever the contact could be located would be a sensible plan? A. No. The drilling should be directed by someone who thoroughly understands the geology of the district.

Q. But even where there is no outcrop, you think drilling might be productive of results? A. Yes, I do. Of course, it is a longer chance, but that is the way it will have to be found. There are possibilities of the extension of the known ore bodies at great depth, and these could only be found by diamond drilling. Perhaps the ore would occur at a depth where it would not be profitable to mine it.

MR. YOUNG: Have you had any experience outside the Sudbury district, in nickel? A. No. In other metals, but not in nickel.

Mr. J. A. Holmes, Mining Engineer, Sudbury

CHAIRMAN: Will you kindly state your connection with this industry. You are interested at the present moment in the British America Nickel Company? A. I am a stockholder. I have no further interest. I was manager of it until they closed down. Before that I was manager of the same properties under the Dominion Nickel-Copper Company. I acquired most of the properties that the British America have now, for the Dominion Nickel-Copper Company, and then effected a sale to the British America people. The Dominion Nickel-Copper Company was a Canadian concern. They formerly bought out what is spoken of locally as the "Hamilton crowd" property—the Whistle property principally—and some other claims on the north range.

Q. It is mainly those which formerly belonged to the Vivians? A. No, it is an entirely different concern. I came here six years ago as consulting metallurgical engineer to the International Nickel Company in connection with the building of a new reverberatory plant at Copper Cliff, and the installing of basic converters, and before that I had been in the west where we had made a success of basic converting in the copper business.

Q. And your experience is metallurgical rather than mining? A. It has been both. I began my practical experience when I was fourteen years old. I went to work in a mine as mucker and miner and timber man, and afterwards went into the smelting end of the business, because the underground work gave me such headaches I could not stand it. I finally went to school, completed my work for two degrees, and then went back to work again.

MR. YOUNG: What degreees are they? A. B.S. and Engineer of Mines.

Q. Where did you get them? A. I took them in the College of Mines, Houghton, Michigan.

Q. When did you graduate? A. I took my engineer's degree in 1905. I worked in metallurgy with the Garfield Smelting Company in Utah, before I came up here.

Q. Then? A. The Dominion Nickel-Copper Company had acquired the Whistle mine and various other claims on the north range, and had been developing them for about four or five years, but they had not had much success. Then I met the president and vice-president of the company—Mr. Booth, of Ottawa, and Mr. O'Brien, of Renfrew—and they asked me about nickel and the nickel business. Of course, I was not able to give them any information at that time, but we struck up rather friendly relations, and the outcome of it was that I went with them, after I had been here a year. At that time they were ready to build a smelting plant. I signed a contract with them, but found out they didn't know anything about what they had. They thought they had a big mine. There has never been another case, in my experience, where investors have gone in and paid such an amount of money as they did for an undeveloped mine without even an engineer's report. They simply went ahead blind, and paid a million and one-half dollars for a rusty looking hill. You asked some questions about magnetic surveys. It may be interesting to you to know that they had followed such a survey in their prospecting work, and got nothing. I wouldn't say that such is always the result, but I know from experience that the ore is not where the indications are that you will get it. The Whistle hill had been punched full of holes during the four years before I went with them, and in about eight months after we got started in a systematic way to try to find what

we had, we developed about a million and a quarter tons of ore; nad we got that by simply going where they had not gone. Where there were indications of ore they didn't get anything.

Q. Then, what is your opinion as to the value of the magnetometric survey? A. I think in certain types of deposits it is valuable. For instance, we found it very valuable in the property in Falconbridge. That particular body proved to be about 60 to 80 feet wide, and by taking a dip needle we were able to determine where the edges of the deposit were; but in no other case have we been able to use it at all. I think the reason for that is, that we didn't know how to interpret the readings that we got. In one place where from the readings we thought we had a lot of ore, and drilled, we could not find anything.

CHAIRMAN: When you say you didn't get anything, you mean you didn't get any nickel or any magnetic ore? A. We didn't get any nickel ore. When I say ore, I mean something we would consider worth putting on record.

Q. You don't mean that the magnet made a mistake? A. No. Undoubtedly there was deflection there, but we didn't get any ore.

Q. Did you learn why that was? A. No, we didn't. We put down several holes, and got no commercial ore or anything that approached it; so we stopped. All the ground is mineralized. You get mineralized ground anywhere in this country.

MR. YOUNG: When was that Dominion Nickel-Copper Company incorporated, do you remember? A. No, I cannot tell you. It must be nine or ten years ago now.

Q. Was it a Dominion charter? A. Yes, Dominion charter.

Q. By letters patent, not by special Act? A. I don't remember about that. This was all previous to my acquaintance with the nickel business at all. They were organized and had been running between four and five years when I got acquainted with them; then we went ahead and drilled most of their properties, and at the end of about eight months reported to them that they weren't justified in going ahead with the erection of a plant; they had not sufficient ore. We advised them to acquire other properties, and they bought out the Lake Superior Corporation's nickel properties first. These consist of the Elsie, Gertrude and Victor mines.

Q. Did you take all of them? A. Yes. The reason we went after them first was that we had an idea that there was a good large deposit of ore at the Murray, and that the big part of it would be on the Elsie. We finally got the Murray and the rest of the Vivian properties, about 3,400 acres.

MR. GIBSON: What other mines were there? A. The Murray is the only mine. There is another prospect that has a name—it is called Lady Violet. The company owns about 17,500 acres in the district; I think there are about twenty-five or twenty-six known deposits, and we drilled eighteen of these. The acquiring of the Murray and Elsie deposit was the saving of the situation for them, and they were quite successful in drilling for ore.

Q. At the Murray? A. The Murray-Elsie; it is one ore body. They were getting about a million tons of ore per month; the last month it was one million six hundred thousand tons, and the reason they stopped was that it was not good business to invest any more money in drilling. They had sufficient ore developed to warrant them going ahead with their enterprise, and before they would need any further ore they would have ample time to do more drilling. It was only a small expense per ton. The total ore at the Murray mine cost them less than two cents per ton to develop. In computing tonnage, the Canadian Copper Company and other companies simply include the ore that has been blocked out in the area actually drilled, and take no credit for anything outside of that block.

CHAIRMAN: Although as a matter of extreme probability the ore would extend on both sides? A. Yes. In fact, as a matter of extreme probability, all these ore bodies increase in depth.

Q. And is the estimate of sixty or seventy million tons of proven ore in this district computed on that exact method, so far as you know? A. So far as I know. There are only a very few drilled properties now that don't belong to one of the three companies.

Q. It is a fair inference that there is very much more ore than that? A. That simply represents the ore that the companies felt it was expedient to have blocked out.

Mr. James Purvis, Merchant, Sudbury

MR. YOUNG: Have you any views respecting the refining of the ore, Mr. Purvis? A. In regard to the refining of ore, I believe with the majority of the residents of the town here and possibly everywhere else, that nickel should be absolutely refined within the Empire. Being a resident here, naturally I would prefer the closer the operations were to the nickel mines, but being a citizen of the Empire, it would satisfy me and should satisfy everybody else, if the refining were done within the Empire.

Q. At a point which would be in the best interests of the parties concerned? A. Yes.

Q. You think that all the demands of patriotism and business would be met if the refining were done anywhere within the borders of the British Empire? A. Yes. This

[*J. A. Holmes; J Purvis.*]

matter a couple of years ago came before our local Board of Trade. It was inclined to be narrow, and to insist that nickel should be refined in the Sudbury district itself. I expressed the views that we should not ask for anything like that, but that if it were done within the British Empire it would be satisfactory—wherever would be the most suitable location or locations.

CHAIRMAN: Do you say, Mr. Purvis, that you passed a resolution to that effect a couple of years ago? A. Well, I don't know that it passed, but there was a good deal of discussion about it.

Q. I was wondering whether we could turn up the record of that discussion? A. Mr. Gorman would be in a position to let you have it, I presume. It is on the records of the Sudbury Board of Trade.

Mr. Russell Cryderman, Mining Prospector, Sudbury

CHAIRMAN: We shall be pleased to receive any information you can give us, Mr. Cryderman. What has your experience been in connection with the nickel industry? A. I have been a prospector on the nickel range on and off for the last twenty years.

Q. Have you had any experience in the development of any of these properties, large or small, or any diamond drillings? A. Not much in diamond drilling. I have worked in some of the mines.

Q. Have those been mainly the developed mines; that is, those belonging to the large companies, or have you worked with any prospecting companies? A. Well, with both. I have worked on some of the larger developments and also the small prospects, surface work.

Q. Have you any opinion as to probable developments in the way of discovering new bodies? A. I don't know that I have, except that there are opportunities for development.

Q. We are anxious to gather, particularly from those who have had experience, the prospects for the discovery of large ore bodies, and of an increase in what we might call the available reserves? A. Well, I think there is a good opportunity to develop further big ore bodies on the range, outside of those that are developed at the present time.

MR. YOUNG: That is north and south? A. Yes, I think both on the north range and the south range, east and west. On the undeveloped parts I think that extensive diamond drilling would disclose large bodies of ore.

Q. That is, you think the whole field that has not been developed holds reasonable promise? A. I think so, yes.

Q. That whenever you find the conditions existing, where large bodies have been proven, there is a good chance of repeating? A. Yes, where similar conditions occur. And even in some of the covered parts of the range along the contact, I think there are places where there are indications of large ore bodies.

CHAIRMAN: I understood one of the witnesses to say that most of the surface showings had been developed? The more pronounced surface showings? A. Well, they are the larger ones. I think there are a very considerable number of promising showings which have not been developed, more especially between the end of the ranges, in Capreol and Norman townships.

MR. GIBSON: Do you speak of those townships as being on the north range, or the easterly range? A. We call it the easterly range.

Q. That is from Massey bay north to the Whistle? A. Yes, or from further south as far as the Falconbridge

Q. Do you include Falconbridge in the east range? A. Well, there is a part of it on the south From the point in Falconbridge where the contact turns north, up to the Whistle, is what we usually refer to as the east range.

MR. YOUNG: How many such indications do you recall? A. There are Ella lake and Clear lake on the eastern range, and what is called Pyrrhotite lake. There are indications all along that section.

Q. Has any drilling been done there at all? A. I think along Pyrrhotite lake there has been some, but I don't know anything about the results in that district. There are good surface showings all along there.

Q. You think they would all justify diamond drilling, do you? A. I think so, yes.

Q. Is that the best method, in your opinion, of proving it up? A. No, I think probably the best method is to sink on these and develop. You may get results by the diamond drill; if you don't, it is not really a test.

Q. It is all right if you get it, but you may miss something which good sinking and drifting would open up for you? A. Yes.

MR. GIBSON: That is much more expensive? A. Yes, the preliminary investigation by diamond drilling is much cheaper.

Q. Are these claims all taken up? A. Yes, they have all been located.

Q. Are there any Crown lands open? A. I don't believe there is much Crown land that gives promise, except probably back from the contact on the dip of the ore some places

Q. But not along the contact? A. No.

Q. So it is just a question of those who have control of these various locations being in some way or other induced to go on and prove them up? A. Yes.

Q. Why is that not being done? A. I suppose, principally because the operating companies here have sufficient ore already in hand.

MR. YOUNG: No particular stimulus? A. No.

Q. In other words, there isn't a market for it at the present time? As far as this district is concerned, the operating companies and the British American company have all the deposits they want? A. I suppose that is it, as far as I know.

Q. Until you get some other interest, financial assistance or capital? A. It is a matter of interesting new capital.

MR. GIBSON: What market would you as a prospector have if you discovered a new property with considerable ore on it? A. Well, I would have to go along and look for somebody.

Q. Is there an active demand for new properties? A. Not that I know of at the present time.

MR. YOUNG: Are any of those you mention or have in mind been proved or developed in any way at all? A. Just surface stripping.

Q. Not enough to enable you to give any estimate as to what might be there in the way of tonnage? A. No, nothing; only the conditions are similar along the contact where other large ore bodies have been developed; but nothing except surface work has been done up to the present time.

Q. Nothing but inviting chances of repeating the experience of others who went ahead and found it under similar conditions? A. Yes.

Q. That is, mainly, on the contact? A. Yes, with pronounced showings of gossan and ore in places.

Q. And the ore that you get is pretty much the same as in the other mines? A. Yes, some pyrrhotite and copper pyrite.

Q. And about the same proportions of nickel and copper? A. I could not say about that, because there hasn't been any assaying to determine it.

MR. GIBSON: Has any quantity of ore been taken out of any of these mines on the eastern ranges? A. No. The Whistle on the northeast corner is the only property that has been developed.

Q. How much ore has that produced? A. I don't believe they have shipped any from there. They simply opened it up.

Q. And left the ore on the heap there? A Yes. I think any that was taken out was left on the heap.

Q. Is that true also of the locations on the north range? A. Yes, I think so. I think when you get east of the Levack mine there has not been any development.

Q. Levack is the only mine developed on the northern range? A. Yes.

Q. There does not seem to be unanimity of opinion or practice in speaking with regard to these so-called ranges. What do you put in the northern, and what in the eastern, range? From what points to what points? A. Well, offhand I could not give it to you, but we speak of the west end of the northern range as being in the township of Cascaden.

Q. Would Trill be in the northern? A. No, I think it would be in the western range, if you might so term it. Trill, I think, is the turning point.

Q. It turns in Trill and swings around to the northeast? A. Well, we usually refer to that as the western range.

Q. How far north? A. From there to Cascaden township, where the northern range turns in a northeasterly direction.

Q. And how far east? A. To the Whistle.

Q. That is the eastern end of the northern range? A. Yes.

Q. And from there south you call it the eastern range? A. Falconbridge is partly on the southern and partly on the eastern.

Q. Which of the properties are on the eastern? A. I don't know which lots, but there is a turn there where it is shown on the map.

Q. There is an old location called M.2? A. Yes, I think that is just after it turns north.

Q. The properties that J. T. Cryderman took up there? A. Well, they are right almost on the corner where it turns. They are right in the corner; the southeast corner of the range.

Q. It is not very important, except to be sure that we know what we are talking about in using these different designations, that is all? A. In referring to the contact after it turns in Falconbridge and goes north, we speak of it as the eastern range, then where it turns west or southwesterly, along to Cascaden, we call that the northern range, and from there south through Trill to the Sultana mine we call it the western range; it turns there again, I think in a southeasterly direction, and we call that the south range, or main range.

MR. YOUNG: I take it, in short, that all the promising ground has been pretty well prospected and located? A. Yes, it is pretty well taken up.

Q. Not much left for the prospector? A. No.

Q. Has all your experience been confined to this district? Have you done any searching for nickel in other parts of Ontario? A. Yes. I did some work on the Transcontinental between Cochrane and Hearst.

Q. And what did you get? A. I found some pyrrhotite on the Opasatica river, but it didn't contain any nickel. The only place I know of where there is nickel in that country is the Alexo mine, and a little over in Munro township.

MR. GIBSON: What is in Munro? A. I haven't seen the property, but I am credibly informed that there is two per cent. sometimes in the pyrrhotite there.

Q. Do you know under what conditions it occurs? A. No.

CHAIRMAN: Is that two per cent. nickel or two per cent. of the two metals? A. No, I understood two per cent. nickel and some copper, but I don't know how much copper they get.

MR. GIBSON: Do you know what part of Munro that is in? A. No.

Mr. James R. Gordon, Mining Engineer, Sudbury

CHAIRMAN: You were kind enough to volunteer to give us some information this afternoon, and we would be pleased to receive it. Perhaps it might be well for you to state first of all just what experience you have had in the nickel business, or any aspect of it? A. I came to this district in 1884, and with the exception of a few years a short time ago, have been interested in prospecting and mining ever since. At the present time it seems to me that a serious question which arose some time ago has practically settled itself. We mining men all over Canada wished that nickel should be refined in Canada. Now, there are perhaps two, three or four companies who are refining or proposing to refine nickel in Canada; so that question seems to have settled itself. These men will invest large sums of money in the refining, and it is up to them to make good. The next question which appeals to me is the control of the nickel after it is refined. Hard things have been said about the International Nickel Company allowing nickel to go to Germany and so forth, which, of course, it did, but I cannot see that they are to blame in any possible way. Before the war, nickel was sold in the open market: anybody could purchase it, and like any other business, it could not be controlled. I spoke to Premier Hearst just before his leaving for England, and suggested a plan which he said was feasible That is, that sales of all nickel refined in Canada be supervised by the government of the day, and that sales be made to individuals, but under the control of the various governments of the world.

Mr. Lawrence O'Connor, Merchant and ex-Mayor of Sudbury

CHAIRMAN: Mr. O'Connor, we shall be pleased to have you give us any information bearing on our investigations? A. The only experience that I have had in the nickel business was as accountant for the Drury Nickel Company in 1892, 1893 and 1894, from the time of their development until the time they undertook to ship high grade nickel matte. They made matte by the Manhès process; it contained about 60 per cent. metal. What I learned about the nickel business then was, that if you did not have a market for your nickel, you had better keep out of the business. Having been a permanent resident of Sudbury since that time and followed the question from a business standpoint, noting the number of new companies that entered the field and were closed up, I felt that the impressions that I gained then were well founded. A short time ago, the agitation for the refining of nickel in Canada was on foot. The stand I took was that if I was right in my early impressions of the nickel business, those who are engaged in the production of nickel must have a market in order to succeed. Further, that if we were to interfere by requiring nickel to be refined in Canada, it might be the cause of jeopardizing the nickel mining industry here. That is to say, those who are engaged to-day in the nickel business have a market: they have the American market and the European market, and if by any legislation that might be passed to compel the refining of nickel here, we were to lose the American market, our nickel industry would be killed. It may probably be only because of the present U.S. tariff conditions that we are producing to-day the amount of nickel we are producing here. What I mean is, that if we were to lose the American market by compelling the refining of nickel in Canada, it might give the European operators the American market. About two years ago several resolutions came up before the Sudbury Board of Trade; the first was that nickel should be refined within the British Empire; the second that it should be refined in the Dominion of Canada; and the third that it should be refined in the Province of Ontario; and the Sudbury Board of Trade, or a majority, favoured the second resolution, but suggested that the government should be asked to appoint a Commission to investigate the nickel industry before any action was taken.

[R. Cryderman; J. R. Gordon; L. O'Connor.]

CHAIRMAN: Is this on record, Mr. O'Connor? A. I think it is on the local records of the Board of Trade of the town of Sudbury.

Q. Can we obtain a copy? A. I think you can. The Associated Boards of Trade passed a resolution approving of the appointment of a Commission, and expressing the hope that the report of the Commission would justify the government in compelling the refining of nickel in Canada.[1] It didn't say the British Empire, but Canada.

Q. Is that also on record? A. Yes. I think everybody in this section of the country is very much in favour of refining in Canada, or in Ontario, provided it isn't going to jeopardize the industries that are here at the present time. Unfortunately, refining nickel in Canada, because of the war, has come to be a patriotic question instead of a business question. The difficulty is, how are you going to mine your ore and make the nickel and market it, and keep it away from the other fellow? That is pretty near a commercial impossibility.

MR. YOUNG: I would like to hear something about that Drury Nickel Company? A. The Drury Nickel Company was operating the Inez mine, which is about five miles north of Worthington. They sank a shaft and built a smelter, and produced a 52 or probably a 55 or 60 per cent. matte. They could not market the matte, and they went on and spent somewhere about $400,000. The whole difficulty was to get a market for the nickel. That is practically in a nutshell what happened to that company—no market for their product.

Q. Was it a Canadian company? A. No, they were Americans from Chicago.

Q. What did happen in the end? A. Joseph Wharton of Philadelphia undertook to smelt some of the ore there and took it down to his works in Camden, N.J., and finally bought the property and turned it over to the International when the amalgamation took place.

Q. Did they have any of their matte refined? A. The Emmens Refining Company of New York were handling the matte and for refining were to get two-thirds of the sale price; and one-third of the amount was to go to the mine.[2] At that time nickel was worth 45 cents a pound, and they figured about 15 cents a pound for the nickel contents would be the share of the mining company; the refiners were to get the balance, but they were to pay all the expenses of selling.

Q. Where was the Emmens Refining Company situated? Youngswood, Pa? A. I forget. They had their office at 54 William Street, New York. The Drury Company shipped somewhere about $100,000 or $200,000 worth of matte, and received no returns, so they went out of business.

Q. No sales? A. There were no sales.

MR. GIBSON: Do you know if the Emmens Company actually refined the matte? A. I don't really know. I don't think they did. I think when Wharton took over the interests of the Drury Nickel Company, whatever nickel was around the Emmens works was sent to his plant.

CHAIRMAN: Supposing the price received for the nickel was 40 cents, would the division still be one-third and two-thirds? A. Yes. At that time the market price of nickel was 45 cents, and that was on the basis of 60 per cent. matte. When they shipped any matte that didn't go any higher than 25 per cent., that is, when it was not Bessemerized, they only got 11 cents a pound.

Q. That meant 60 per cent. nickel plus copper? A Yes.

MR. GIBSON: Did they get anything for the copper? A. There was a basis, but I don't remember what it was.

Mr. Thomas Travers, re-called

MR. TRAVERS: I should like to make a statement if I may. Mr. O'Connor, I think, was mistaken in saying that the refining company got two-thirds and the mining company one-third. They got 30 cents for the nickel contents, and nothing for the copper. There was very little copper in that mine. Dr. Emmens owned a refinery, and it was he who entered into this contract with the Drury Nickel Company. His process was a failure, and his company failed; the Drury Nickel Company's matte was in his possession and they replevined it, but when they got it—it was just during the time of the big panic—they could not dispose of it for any value. I think they got eleven cents a pound for nickel contents in New York, and during the time they were waiting for returns they were obliged to close up.

Q. What became of the company? A. The property was leased. After the Emmens Metal Company failed and the panic was partly over, Wharton advanced money to start things up again, but not enough to carry on the business, and he took a mortgage on everything that was on the place. When I became Mr. Wharton's Canadian agent, the Drury Nickel Company shut up, and I bought ten thousand tons of ore from the Vivians that was in the roast yard at the Murray mine, and smelted it and shipped the matte to the refinery in New Jersey. I didn't use the Murray smelter: I used the one that was built for the Chicago mine. I made a low grade matte from the Murray ore, containing 20 to 25 per cent. of nickel plus copper contents. After finishing at the Murray mine, I took the smelter back to the Chicago mine and smelted the ore that was in the roast yard there. Shortly after that the

[1] For resolution, see foot-note p 13.

[2] See evidence of Mr Travers, re called

International Nickel Company was formed, and all of Mr. Wharton's holdings went to the International Nickel Company.

Q. Well, if it was only a lease that the company had, how could they transfer it? A. The lease someway was bought. It was a lease and an option, and I think when Mr. Wharton took this mortgage and was closing, he took up the option.

EVIDENCE AT COBALT, 28TH SEPTEMBER, 1916

Arthur A. Cole, Mining Engineer, Temiskaming and Northern Ontario Railway, and President Canadian Mining Institute, Cobalt

MR. GIBSON: Speaking first with regard to nickel in the Cobalt ores, can you give us any information about that? A. In a statement that was prepared a short time ago we showed that of the silver that was produced in this camp, 16 per cent. went out of the Province as ore for treatment: the balance was all treated in Canadian smelters or high grade plants here on the ground. That 16 per cent. which is exported would contain a certain amount of nickel and cobalt and arsenic which is lost to the Province, but since that is, in a good many cases, in low grade ores, it would not be available in any case.

MR. YOUNG: Even if it were refined here? A. Even if it were refined here.

Q. It would not be fair to say that 16 per cent. of the nickel in the Cobalt ores left the Province? A. I should think so, but I haven't any figures to place before you as to that, and it would be very difficult to obtain them. There is a certain amount of nickel which it would not pay to take out of the ordinary ores, and a good deal in the material that is very low grade and used as a flux is lost absolutely.

Q. Is there any nickel in that 16 per cent. that goes to the United States? A. I think there is a certain amount of nickel in the ore, but I do not know how much.

MR. GIBSON: Will the flotation process be likely to lead to a further recovery of the nickel? A. I don't think so, because in most cases the oils won't float the arsenides, so for the most part they are free from nickel and cobalt. They are already practically lost, and they will not be recovered by flotation.

Q. That statement would apply to the cobalt as well as the nickel? A. Yes.

Q. Have you ever made any inquiry with regard to the average percentage of nickel in the ores of Cobalt as they are produced? A. I have no figures on that.

Q. Do the mine owners assay them for nickel? A. Some of the smelter statements may show that, but not for any that goes out of the country.

Q. The mine owners are not paid for the nickel contents of their ores? A. No.

Q. In some cases are they paid for the cobalt? A. I understand some of the Canadian works pay for it under certain conditions, but for ore that goes to the United States no payment is made except for the silver.

Lieut.-Col. R. W. Leonard, President Coniagas Mines Limited, St. Catharines

MR. YOUNG: Colonel Leonard, is there anything you can give us now, taking up nickel first? A. With regard to the percentage of nickel in the ores, probably the best information available is that in the Mines Department in Ontario. Some of the higher grade ores will run up: they vary a very great deal; possibly four or five per cent. of nickel would be the output of some of the higher grade of the mines and from that down.

MR. GIBSON: There is less in the poorer quality of ore? A. Yes, a little, but I am speaking of the output of the mines as a whole, and of the shipments month in and month out.

Q. In low grade rock from the walls of the vein, you would not expect to find much arsenide? A. Possibly a half per cent. or something, which we never recover. It is lost in the slags.

Q. In your reduction works you do recover a good deal of nickel from the ores you treat? A. We do recover the nickel with the exception of the ordinary smelting loss; this we have disposed of from time to time in the form of nickel oxide, the details of which are in your Department.

Q. Have you made any metallic nickel? A. We have recently made some with an electric furnace, experimentally, but I think I am right in saying we have not shipped any metallic nickel at all.

Q. Are the losses of nickel in your works, or any works, considerable or slight? A. They are very material, but I cannot from memory give you the exact figures. I may say that by our process we practically have to save the nickel, but that it is spending a dollar to get a dollar. There is no profit in it.

Q. It is a metallurgical necessity? A. In our process.

[A. A Cole; R. W. Leonard.]

MR. YOUNG: What would be the extent of the nickel that is recovered from the sixteen per cent. of the Cobalt camp output of ore that goes to the United States? Is it a factor at all in the nickel production of the United States? A. I doubt it. As Mr. Cole stated, a great deal of the ore that goes to the United States is probably very low in nickel and cobalt, but some of the ore contains a material quantity of both: not so much in the last year or two as in previous years; however, I have no knowledge that any of it is recovered in the United States.

MR. GIBSON: Is it your impression that it is disregarded there? A. My impression is that it is wasted: all of it.

MR. YOUNG: I suppose a stage could be reached in the prices where it might be worth while commercially to refine some of that ore? Would the quantities and cost make it commercially desirable to do so? A. Those ores are purchased by smelters who are essentially silver-lead smelters, and the amount they purchase is so small as compared with their whole business, that by-products such as cobalt and nickel are practically negligible to them. I don't think they pay any attention to them at all, speaking generally.

MR. GIBSON: What makes the ore that is sent to these smelters from Cobalt desirable for their purposes? A. In some cases it is the silicious character of the ore which is valuable, with the basic ores for a flux. In other cases it is the rich silver values which probably sweeten up their lower grade ore.

MR. YOUNG: Do you know anything as to the quantity of nickel that they get as a by-product in the United States at large? A. I do not.

Q. We would have to go to the statistics for that, such as they are? A. I don't know where you would get them.

Practicable to Refine in Ontario

Q. We would be very glad to have your views with respect to the important question of refining in Ontario, if you care to implement your contributions to the *Mining Journal* on that subject? A. I don't think I can say very much more about that than what I have said. I have gone into the matter in a fairly careful way with my staff at the smelter, and I have made up my mind that there is no reason why nickel cannot be economically refined in Ontario or Canada, and probably to compete with anything that is capable of being done in the vicinity of New York. Apart from the actual labour involved in the refinery itself, it would give a tremendous stimulus to the manufacture of re-agents such as acids and other necessary substances, and would be of enormous benefit to the Province. I am very strongly opposed to locating such an industry, which is so essential to munitions work, so close to the international boundary as Port Colborne, where, according to the newspapers, it is proposed to locate the International Nickel Company's new refinery, and where it would be peculiarly vulnerable to attacks by sympathizers in the United States of any European country with which the Empire might be involved. At that point they would probably also use Niagara power, which is right on the boundary, and very vulnerable to disturbance by enemy sympathizers

Q. Do you think the danger of disturbance between Canada or Great Britain and the United States is appreciable, and should be considered as a factor in the location of the refinery? A. These are purely matters of opinion, and I suppose three years ago nine-tenths of the population of this country and of England would have laughed at the idea of a war such as we are now having. We at present would laugh at any suggestion of trouble between Great Britain and the United States, but other times, other manners: we don't know.

Q. You think it is best to be on the safe side? A. I like to be on the safe side.

Q And be prepared for every contingency? A. Yes. It would be a most regrettable thing. We have had a hundred years of peace, and we all hope we may have a thousand years more.

Q. As a citizen of the Province, are you satisfied with the refining of nickel in Great Britain by one of the large companies? A. As a citizen of the Province, of course, I would like to see the refining done in the Province, if it accords with international requirements: then, if not, somewhere else in Canada: if not in Canada, then anywhere else in the Empire rather than in a foreign country.

Q. That is the order of your preference: Ontario, Canada and the British Empire? A. Yes.

Q. And in Ontario at a point, industrially possible, as far away from the boundary as can be secured? A. Yes. That is my preference.

Q. But, of course, that will have to be determined by the necessities of the process? A Doubtless

Q The argument is advanced that it is desirable to have refining facilities in England itself, or say in Wales, with an accumulated stock of matte there, to provide against accidents, momentary losses at sea, or anything of that sort, and I take it you are rather inclined to appreciate that line of reasoning? A. Yes. It involves economical calculations on which I am not qualified to express an opinion, but it looks to me as if that might be a reasonable thing from the Empire point of view.

[*R. W. Leonard*]

Refinery should not be on Boundary

Q. I was rather following your own reasoning along the strategical situation; there is something to be said in favour of refining in Great Britain with an accumulation of matte there for any emergency? A. Yes. Every British subject who has considered the subject will probably agree that the supply of such an essential element in war munitions as nickel, and so vital to the safety of the Empire, should not be dependent upon refineries located in foreign countries, and, therefore, it is better to have a refinery established anywhere in British territory. Again, every intelligent person will agree that such a refinery should be established in a safe part of the Empire, where it could not easily be damaged or destroyed by a possible enemy either acting as a nation, or by possible raiders from a neutral country. The newspapers report that the International Nickel Company have selected Port Colborne, Ontario, as a site for a refinery to manufacture nickel for the British Empire. Port Colborne is on the shore of Lake Erie at the south end of the Welland Canal. It is within long range gun fire of United States territory, and especially vulnerable from Lake Erie, which here forms part of the international boundary, and of course equally vulnerable to bombs dropped from dirigibles, aeroplanes or hydroplanes, and most accessible to raiders over the border. It is also announced that the British America Nickel Company is contemplating building immediately a similar plant to treat ores from its Sudbury properties. It is to be hoped that the location of this proposed plant will not be in the southern peninsula of Ontario, for the same reasons. I am fully alive to the necessity of producing nickel in British dominions for national safety; recognize the desirability of losing no further valuable time in this matter; recognize the natural wish of the Province of Ontario to have the refining of nickel done in that Province; but am also equally alive to the probable danger of the popular hysteria and resultant agitation hustling the government into unnecessary and undignified haste in determining the details of the project before receiving the report of its Commissioners, and to the national crime of locating its refinery works, or of allowing them to be located, in possibly the most vulnerable point in Canada. The fate of the Empire may some day well depend on the wisdom now displayed by the authorities in dealing with the question.

Mr. Samuel W. Cohen, General Manager, Crown Reserve Mining Company, Limited, Cobalt

MR. GIBSON: Have you any opinion as to the refining of nickel in Ontario, Mr. Cohen? A. As to the refining of nickel in Ontario, in forcing that as a measure, I think there are certain dangers. For instance, suppose we have a little nickel mine we want to work, not big enough to build a refinery for, but good enough to warrant putting in a little matting furnace—and there are lots of places we can sell the matte—if it had to be refined in Canada we would have to sell it to the Mond or the International Nickel Company, and if they didn't choose to take it from us, they would tell us to go jump in the lake. We would have to quit.

Q. What would you suggest in that contingency? A. Well, I don't know. The thing is a pretty big question. Nickel seems to require special consideration as compared with other metals, because of its use in war. Therefore it should be controlled.

Q. It is an enormous industry apart from war uses? A. In the special conditions that exist, the first consideration right now is that you should control it, and perhaps of necessity have enough nickel for your purposes refined where you can get it as you require it, but compelling its refining here would raise just such difficulties as I have suggested, and would be a hardship in certain cases.

MR. YOUNG: A custom refinery, I assume, would meet that? A. If the Government put up a refinery, there is no reason in the world why a man could not get all his nickel refined here.

Q. Have you had any special experience in nickel? A. Well, I have had a little along those lines, but not in the way of refining.

Mr. Tom R. Jones, General Manager, Buffalo Mines, Limited, Cobalt

MR. YOUNG: Mr. Jones, have you anything to say in regard to nickel in Cobalt? A. The only thing I have to say is that at the Buffalo mine we have got our nickel, practically all we have produced.

Q. You have got it all? A. Practically all we have mined for the last four or five years, except what has been sold. We have on hand approximately 2,600 tons of residues in the form of ground smaltite, which will pass 100-mesh and which contain say 156,000 ounces of silver, 117,000 lbs. of nickel, 270,000 lbs. of cobalt, and 918,000 lbs. of arsenic. This is all recoverable. In addition we have sold 326 tons, which would run about 5 per cent. cobalt, 2.5 per cent. nickel, and 17 per cent. arsenic.

Q. As to the flotation process, what have you to say as to the effect of that? A. It will not recover nickel in cobalt arsenides, but it will recover a copper content which will compensate you for it.

[R. W. Leonard; S. W. Cohen; T. R. Jones.]

Mr. Alexander Kelso, Discoverer of the Alexo Mine, Goldlands

MR. YOUNG: Well, Mr. Kelso, we would be very glad indeed to hear anything you have to say in regard to nickel? A. Well, that is what I am much interested in, and I have great confidence in the possibilities of the country if we had a better chance for development.

Q. What do you base that confidence on? A. We have been working the Alexo mine and selling the ore to the Mond Nickel Company. What enabled us to keep working was the high grade of the ore. When the Mond Nickel Company made the agreement with us to buy our ore, it was stipulated that the ore was not to average under four per cent. nickel. Well, our output has averaged considerably higher than four per cent. We shipped about twelve thousand tons out in 1915; it was in development work really that that ore was procured, sinking and drifting and proving up, and it averaged about 4.90 per cent. of nickel and about .60 copper. There has been nickel discovered in South Bay.

MR. YOUNG: Where is South Bay? A. In the townships of Langmuir and Carman, on Night Hawk lake.

Q. When? A. Well, it has been known for some time, a low grade ore. I understand that this year some high grade ore has been discovered there.

MR. GIBSON: Are you aware of any large body? A. In the township of McCart, no; the ore was low grade mostly.

MR. YOUNG: What are you speaking of now, Night Hawk Lake? A. Night Hawk Lake, township of McCart and the township of Munro.

Q. Where is the mine in Munro? A. Near the Beatty boundary. A man named Mickle, a lumberman, had it. He came with samples about a year ago into the Alexo mine and said they ran about 2½ per cent.

Q. How much copper? A. I don't know.

MR. GIBSON: Did it resemble the Alexo ore? A. Exactly, but the grade was lower.

Q. Nothing was known as to the size of the body? A. No.

Q. Did he get the outcrop there? A. Well, he said the outcrop appeared and re-appeared from under the drift for quite a distance, but it was really an undeveloped prospect at the time.

Q. Has anything been done on it since? A. Well, I couldn't tell you: I understood that he was prospecting for nickel this summer.

MR. YOUNG: Have you done any prospecting up there yourself? A. Not in Munro; but about two miles from the Alexo mine there is an immense deposit of white serpentine that carries nickel, chrome and magnetic iron, and there are millions of tons in sight.

MR. GIBSON: Has it been sunk on at all? A. No, just on the surface where it appears by the drift.

Q. How does it run? A. About 13 per cent. magnetic iron, .47 per cent. nickel, and 2.70 per cent. chrome. Campbell and Deyell of Cobalt made the assay, and the question occurred to me, could a body like that be concentrated at a profit for the production of nickel-chrome steel?

Q. Have any other bodies of ore been found on the same contact as the Alexo mine? A. None so far that are workable. There has been float discovered on the drift as it dipped. That is on another contact, about two miles further south or thereabouts from where this deposit of chrome-nickel is.

Q. That is the one you have just mentioned to us? A. Yes. There is a second part that runs parallel to the first about two miles further south, right across the township of Dundonald and a good part of the township of Clergue; you pass the centre of the two in concession one.

MR. GIBSON: Any ore bodies located? A. No: it would require a drill to test these.

MR. YOUNG: The drift is very heavy? A. Yes, it is capped very heavily. Very high peaks and rocky sections occur here and there, but the serpentine being worn away, the ore appears on the surface at the contact of some soft and some very hard rock.

MR. GIBSON: Have you any other suggestion with regard to the nickel industry? A. No, except that it would stimulate the working and prospecting if there was a custom smelter or refinery at a point, say, not far from Cobalt or Sudbury, which would buy the ore and concentrates from the prospectors and mines that will ultimately develop in this north country.

Q. You think that the small owners would be thus enabled to work their properties and get a market for their ore? A. That is what I think. As it is, the industry is practically under a ban owing to the conditions.

Q. Could the ore or matte be sold? A. That is what we haven't gone into particularly. I think that if a custom smelter was established, or if there was a refinery, the matte could be sold.

MR. YOUNG: Something would depend upon the requirements and control of the market, and other factors? A. Yes.

Q. Do you know of any other promising deposits in the Alexo district, apart from these you have mentioned? A. No; as a rule nickel has not been given the same attention as gold.

[*A. Kelso.*]

Q. Haven't you prospected that country yourself, pretty well? A. Yes, I have, but owing to the drift it is very hard to prospect, and we were so busily engaged developing our Alexo prospect and making a mine out of it, that we couldn't give attention to a great area of the country. I have seen serpentine in a good many different sections, and of late, this summer especially, discoveries have been made in McCart. Mr. Baker, geologist for the Bureau of Mines, was examining the area for some time this summer, and his report would give you the information even better than I could. He discovered chrome in one section of that deposit that I have mentioned, and got some samples of pure chrome ore. Of course, they were only samples, but they showed the possibilities.

MR. GIBSON: Have you thoroughly prospected the Alexo deposit? A. Well, it would require a great deal more work. We are at present going down from the 150-foot level to the 200-foot level.

Q. You have not ascertained the amount of ore you have in reserve? A. No. The greatest width of ore that we struck was 41 feet. It runs from about 3 feet up to 30.

Q. Does it seem to fade away into the serpentine? A. Yes. Of the ore that we shipped, about two-thirds was mixed with serpentine. An assay of the unmixed ore would show 7 or 8 per cent. nickel.

Mr. W. G. A. Wood, Mining Prospector, Haileybury

MR. GIBSON: Where do you live, Mr. Wood? A. Haileybury.

MR. YOUNG: Prospector? A. Yes. I represent the Wright-Wood Syndicate.

Q. We would be glad to hear what you have to say about nickel in this Province? A. Well, I will confine myself to the Alexo mine. At the present time the prospects there look very good. Searches we have made this summer have located an extensive belt of promising appearance.

Q. Have you been out yourself? A. Yes, sir, along with others I have been out prospecting, especially in Calvert township.

Q. Have you made any discoveries? A. The formation in Calvert township looks favourable. That is as far as we have gone.

Q. No actual bodies yet? A. No, absolutely none. In McCart township they have a low percentage of nickel.

Q. Is that Dan. O'Connor's? A. Yes. But chiefly sulphide rather than ore has been found up to the present time. There are possibilities of nickel as well in Langmuir township, which is south of the Alexo property. We are at present working a property there.

Q. Who is? A. Mr. Reamsbottom, who contemplates diamond drilling. An assay which I got from some of this ore went as high as twelve per cent. Of course, that is not to be taken as average.

Q. Any copper in it? A. I could not say as to the contents in copper. These properties that I speak of are absolutely in the prospecting stage at the present time. Our chief difficulty is to induce capital to work the claims, and the reason is that we really have no outlet for our ore. There are at present only two places in Canada within reasonable distance to which we can ship our ore, namely, the Mond Nickel Company and the International Nickel Company. If these two companies don't wish to buy our ore, we simply cannot dispose of it; there is no other possibility of getting it away at all; therefore it is hard for us to go and raise capital. If we could get a smelter and refinery from the government, it would be no trouble for us to raise what capital we need for developing the prospects. We may or may not make mines, outside of the Alexo, but we can certainly make a try; and we haven't really gone far enough in the prospecting stage yet to determine whether we can or cannot.

MR. GIBSON: Would you consider it reasonable to ask the government to establish a smelter before supplies of ore are assured? A. No, but I think the government know there is already enough ore known to exist, such as the Mond Nickel Company and the International. If they would refine that instead of sending it to New Jersey, they could refine our ore as well at the same time.

Q. Is there anything further you would like to say? A. I don't think so. In regard to the location of the smelter, I would leave that to men who are better posted than myself.

Mr. C. V. Corless, Manager, The Mond Nickel Company, Limited, Coniston

(Toronto, 13th October, 1916.)

[NOTE.—A list of questions respecting the Mond Nickel Company, Limited, its operations, methods, etc, was handed to Mr. Corless at the beginning of the Commission's inquiry. These were carefully and satisfactorily answered. Other points which arose as the inquiry proceeded were dealt with by correspondence or personal interview. In order to complete the data regarding the company, Mr. Corless attended a meeting of the Commission at Toronto in October, 1916 Part of his testimony then given is printed below, and part will be found under Section N, respecting Taxation of Mines.]

[*A. Kelso; W G. A. Wood; C. V. Corless.*]

CHAIRMAN: I think, Mr. Corless, the first thing we should like to ask you about is the several memoranda that we have received from you and from the London office of the Mond Company. We wished to know whether you have anything to add to these, and also whether you desire all or so much of them as we thought advisable, to be printed? A. I did not prepare these memoranda with a view to their publication, but I have striven to present the Mond Company's point of view, and as to the publishing of what I have submitted, the best I can do is to leave the matter to the judgment of the Commissioners. If anything is private and confidential, you will not publish it; otherwise, I would say it is yours to make use of in any way you like.

Further Important Discoveries Unlikely

Q. What is your estimate of the ore reserves in the Sudbury district? A. I feel that at the recent public meeting of the Commission at Sudbury an impression of exaggerated possibility of finding further nickeliferous ore bodies in the district was created. While the use of dip-needles had been earlier introduced, our company was the first to make use of the more delicate magnetometer in this district, and have found it of valuable service. Negative results except over areas very deeply covered with drift or water, may be accepted as practically conclusive evidence that no pyrrhotite of any consequence exists. On the other hand, positive results have to be interpreted in the light of experience gained locally, and even when most favourable, must be followed by drilling or other exploratory work, before being accepted as evidence of an ore body. Very detailed exploration work during the past ten years, not only by the two operating companies, but by outside parties as well, has been done both with the magnetometer and the diamond drill, on the most favourable locations, and so far as I am aware—and I have followed the matter closely—not more than one workable ore body has been found that was not known to exist before, and this one is probably quite unimportant. The diamond drilling has, in some cases, found important extensions downward of the known ore bodies, but in others has proven quite disappointing. Our company has carried on careful exploratory work over a long period, and we are confident that very few, if any, wholly new discoveries will be made in the district in the future. Hope springs eternal in the breast of the prospector, but the only really reliable information must necessarily come from those who have spent the money on exploration and have kept accurate record of the results.

The figures given by Mayor Travers, namely, that sixty or seventy millions of tons of ore have been proven in the district, are as nearly correct as possible. In interpreting these, we must consider that the largest known ore bodies have been fully outlined to depths of 1,000 to 2,000 feet; probably 1,500 to 1,600 feet is a fair average. Some are known to pinch out definitely before this depth is reached. It is a fair inference that others will pinch out or become unworkable as greater depths are explored. If we assume the deepest may prove workable to 5,000 feet depth, and that an average of one-half as much ore per vertical foot of depth for the last 3,000 feet will prove extractable, as was found in the first 2,000 feet, we have gone about as far as any reasonably sound judgment will allow. The discovery of any more ore bodies of the lesser class will not appreciably affect the general result. It seems, therefore, that the district may as a whole produce as much as 150,000,000 tons of mineable ore. But these figures are very optimistic, and are based on complete extraction, which is seldom possible at these greater depths. They might be badly upset by the entire failure of one or more of the largest ore bodies at say under 3,000 feet depth. If the general shrinkage in productivity per foot increase in depth for the last 3,000 feet may be inferred from that of the first 2,000 feet, then the district as a whole may produce as much as 150,000,000 tons of ore. There is, however, practically no evidence as to conditions between 2,000 and 5,000 feet depth, and very little evidence between 1,500 and 2,000 feet. Hence it may be seen that at least the last 50,000,000 tons of the above figure is merely a speculative possibility.

Q. I think you have told us that the dressing and flotation tests that you are doing give great promise. Suppose these were carried out on a large scale, would they lead to a considerable increase in the available ore reserves by allowing the material which is now rejected to be dressed and sent along to the smelter? A. I would say on the mines now being worked the total saving would be not very great, but I regard the mine as having the greatest promise in that direction as the Frood, which is not now being worked.

Q. That is what you call the Frood Extension? A. Yes.

Q. And those remarks would refer also to the main Frood? A. Well, I would not like to speak of our neighbours' property, because I haven't their assays. The ore is very silicious for this district.

Q. And the estimate you have given as to available reserves in the Sudbury district—would it be increased appreciably? A. No, I don't think so.

Q. Suppose we take 100 million tons, how much nickel do you think we could take as the average? A. Oh, that would be a very difficult matter to say.

Q. We have had several figures given to us which vary quite a bit? A. The influence of Creighton on a figure like that is very great, although its tonnage isn't so large as Frood.

[*C. V. Corless*]

Q. As a matter of fact, I have been counting 3 per cent. of nickel and 1½ per cent. of copper? A. How many tons do you take for Creighton?

Q. Something under twenty millions; seventeen millions, I think? A. And how much nickel do you take in that?

Q. I think I took 3 per cent. We could ignore the copper and just take the nickel, it wouldn't matter, would it? A. Creighton has such a big influence on it, that it is very difficult to say. A slight mistake on Creighton would make a big difference. You think about 1½ per cent. of copper?

Q. Yes. A. I don't think you are very far out. I think my figure would be close to yours, with slightly less of nickel. I have not gone into the matter very carefully, but I think the figure you mention is somewhere near correct. But I think that the nickel is a little less than the figure you mention; I would rather be inclined to put the nickel a little lower, possibly as low as 2.8 per cent. But as I say, our data are incomplete. We know the tonnage that is reported from other mines much better than we know the assay, except, of course, in the case of the British America Nickel Corporation, whose assay I am not entitled to make use of.

Q. I notice in one of your reports you say you roast about 30 per cent. of the total ore on the heaps? A. Yes.

Q. Now that, I presume, is still less to-day? A. No, not particularly; I should say that is about right.

The Sulphur Question

Q. Have you any reason to think that your system of roasting in the winter is going to be thoroughly satisfactory, or will it take you time to find out? A. We won't know that until we light our heaps. The only trouble I anticipate is in attempting to light the wet wood under the heaps. We don't intend to light the heaps until the first of November.

Q. But as regards the complaints and damage to agriculture? A. I don't imagine it will lessen the complaints, but it will certainly lessen the damage.

Q. And you have already reduced the damage, I understand, this summer? A. We have practically done no damage this summer. Notwithstanding the complaints, the damage is practically nil. I could not say it is absolutely nil. There is very slight damage here and there, and certain damage near the smelter, but it is practically negligible.

Q. And the sulphuric acid ultimately produced from it in the air, that goes into the snow and does no harm at all, does it? I mean you take it for granted that it does no harm, being produced in the winter? A. We believe the gases do no harm, and the diffusion is very, very wide. The total amount deposited on any given area, that is, beyond our own lands, is very small indeed. But I don't believe that it is deposited as sulphuric acid. There may be a doubt about that. I might just say in connection with that, that we are doing a little experimenting to see what is the effect on soil; the investigations, as you probably know better than I do, that have taken place, are practically unanimous in the conclusion that no damage to the soil is done.

Q. By the sulphuric acid? A. No, I mean by the fumes from the smelters. I don't know of any short report that summarizes the subject in a better way and has a wider scope than Fulton's report, published by the Department of the Interior of the United States in 1915.

Q. The one called "Metallurgical Smoke"? A. That is it. You will find in that that there is practically a concurrence of opinion that no damage is done to the soil. And I looked the matter up in the Transactions of the American Institute of Mining Engineers; it runs all the way through, as you know. There is one volume that has a great deal on it. There is a general unanimity of opinion on this question of soil in everything I have read.

Q. Yes, we have gone through all those reports, including the Selby Commission's report. There is one thing that interests me very much in connection with the roast heaps. Have you done any experimenting to see what losses occur through leaching, either as a whole or in certain parts, either laboratory experiments or otherwise? A. We thought at one time that the leaching from the old yard might be sufficient to be worth while precipitating the metals in it. We used scrap iron and attempted to precipitate them, and used a little lime, but we didn't get enough to make it worth while dealing with it at all. In fact, we never took our scrap up. There wasn't enough precipitate to be worth saving.

Q. Would there be bigger losses of copper or of nickel? A. We are not certain of that, but I am inclined to think the copper would leach a little more than the nickel. I think so, but I am not certain. We are not working in the direction of trying to find out what our losses are now in the yard, because we hope to abandon the yard, and it isn't a live issue on that account.

Q. And how do you find the product from the roast heaps to compare with that from the Dwight-Lloyd roaster? A. We find them practically interchangeable in the furnace.

Q. Then, you have considered the question of utilizing the sulphur? A. Of course, we cannot utilize the sulphur, until there is use for the material after it is saved. I have looked

[*C. V. Corless.*]

into the saving of sulphur for the industry that is there, and find at present it could not be profitably done.

Q. It would depend entirely on the growth of the present industries, or the starting of new industries? A. Or the starting of some new industries, yes.

Q. I see the Northwich Company are starting an alkali works in Canada? A. Yes, I see they are.

Q. As regards the precious metals; in a letter that I have received from the Mond Company in London, dated July 4th, 1916, speaking of the rare metals, they say that they consider in the company's present known ore reserves these metals represent a value of under three shillings per ton of ore? A. Yes.

Q. Would that mean the platinum metals, or would it mean the whole of the precious metals? A. That would mean all of them, I presume.

Q. You see, it says the value of the rare metals, and I was wondering which we could take it as meaning? A. Well, of course, the rare metals certainly include gold. The only doubtful metal is silver, and that is negligible.

Q. Then, the three shillings, or rather seventy cents in Canada, would cover all the precious metals? A. I believe it would, yes.

Loss of Metals in Treatment

MR. GIBSON: Mr. Corless, in memorandum No. II, furnished by the Mond Nickel Company, it is stated that the metallurgical loss in combined nickel and copper is about half of one per cent.? Now, for my own information, I would like to know if that varies in any way according to the grade of the ore, or is that practically constant for all grades of ore? A. I would have to get the context of that to see. It requires a good deal of figuring in the case of concentrating. The first loss would probably be quite low, but on top of that, no matter how carefully you carry on your next operation, you have a considerable dust loss, even if you use the most modern method of precipitating the dust, which we intend to use; and you have in addition the slag loss. So I rather think when you come to figure the two together, your total loss is not much less. I think that figure is as close as I can get to it.

Q. So it is practically constant regardless of the class of ore? A. Yes; it is quite true if you have a low grade ore and are contented to make a low grade matte, you can get considerably less slag loss; and if you have a high grade ore and want a high grade matte, you will get more slag loss. Speaking generally, it is not far from true for total metallurgical loss including cobalt. Of course, that is intended to include all metallurgical losses. For instance, our slag loss is not the total loss. The difference between the metal you start with on the railway siding and the metal you get out in your barrels is considerably more than the slag loss. Some of it we call unaccountable loss.

CHAIRMAN: Then, another thing I was going to ask you. I don't think we have any statement from you, as we have from others, as to losses in this department and that department and so on. Would you agree to have that published? A. Well, I don't think anybody in the district knows what the loss in this department and the loss in that department are. We might make a guess at it. We have never used a sampling plant, and the reason we don't is that we treat mainly our own ores, and the expense of sampling would not save us anything. If we should only sample, say, every tenth carload with our quite variable ores. we would be quite wide of the mark and would create additional fines. We have, therefore, felt that we were not justified in the expense of complicated sampling.

Q. In the same memorandum, you speak of experiments that the Mond Nickel Company have been carrying on with the concentration of low grade ores, and you say that they hope to be able to treat eventually with profit ores of 1½ per cent. grade or possibly lower? A. Yes, of ores already mined that would otherwise be rejected as waste.

Q. That 1½ per cent. is combined? A. Yes. When we speak broadly in that way, we mean combined nickel and copper.

Q. That is quite considerably under the present treatable grade? A. Oh, yes. It would be absolutely impossible at present to treat 1½ per cent. ore at a profit, because of the fact that the fluxing cost would be much too high. In fact, if anyone offered 1½ per cent. ore free, it would not pay to treat it by direct smelting owing to cost of flux. What we do with low grade ore at present, which we don't treat in our experimental concentrating mill, is to pile it up for the future. We haven't piled up very much; we are treating probably twelve to fifteen hundred tons a month, and forty or fifty thousand tons have been accumulated up to the present.

Q. Of course, I understood you intended to treat mainly the Frood mine ore? A. Yes.

[C. V. Corless.]

Mr. A. D. Miles, President Canadian Copper Company, Copper Cliff [1]

(Toronto, 22nd December, 1916)

Tonnage of Ore Reserves

DR. MILLER: Mr. Miles, what can you say as to the known ore reserves of the Sudbury district? A. That, of course, must be more or less an estimate; I would say roughly that there are between sixty-five and seventy million tons in the district.

Q. That is, of proven ore or, as they sometimes call it, "positive" ore? A. No, I would not say positive ore, but probable ore. I would not say proven ore.

Q. Down to a certain definite level? A. Yes.

Q. What estimate would you put roughly on the positive or proven ore? A. That depends entirely on what you mean by proven ore. If you accept diamond drilling as proof of ore, that is one thing. Diamond drilling is not proven ore, but it is probable ore. If you accept diamond drilling records as probable ore, I would say there are at least sixty million tons indicated by diamond drilling.

Q. That is the way in which the ore is "blocked out" in the Sudbury area. In many cases they use that term? A. I don't think you can say it is blocked out. By blocked out we mean developed by sinking and drifting.

Q. In a really large ore body diamond drilling is fairly satisfactory for instance, as in the case of the Michigan and Minnesota iron deposits? A. Yes, we have found it perfectly satisfactory.

Q. So that what you would call probable ore would be almost positive or practically positive ore; where the deposit has been thoroughly drilled? A. Yes, it would.

Q. In that district; but if you were dealing with narrower deposits, ordinary veins, you could not say that? A. No, and you could not say it as regards the smaller deposits of that same district.

Q. But on a body like the Creighton or No. 3? A. Yes, in those cases I would accept that as proven ore.

Q. I think the company has publicly made some statement as to the quantity of ore that has been practically proven in the various deposits; would you mind giving us some information along that line? I would like to have the figures as to the main deposits, Creighton, Crean Hill and No. 3, and probably some of the others that are not working at present? A. We estimate 57,000,000 tons of payable ore, say 10,000,000 tons in Creighton, 2,000,000 tons in Crean Hill, and 45,000,000 tons in No. 3. We have not included in that any ore aside from Creighton, No. 3, and Crean Hill. In addition there is the Stobie, and the old Copper Cliff mine, and the Evans; undoubtedly there is ore in all of them, but it is not sufficiently proven to make any record of it.

Q. It could be said from the experience of the Canadian Copper Company that practically no ore body there of any size has really given out? A. Yes, that is true, with but one exception, that is the Evans. The Evans apparently gave out completely at about 300 feet; however, we are of the opinion that it was due to a fault.

Q. Yes, that is what I should think, due to a fault. And the reason that the Copper Cliff and some of the other deposits are not worked at present is simply that you can get the ore more cheaply from the other deposits? A. Yes.

Q. The Copper Cliff ore is known to be very rich? A. Very high grade, but a comparatively small deposit, and the workings are deep.

MR. YOUNG: You told us at Sudbury that the estimate by your company of your ore reserves was very conservative? A. Yes, I think so, and I base that on our experience in opening up Creighton after we had diamond drilled it. We found the estimate had been conservative, as the levels were developed.

Q. And you also said there was no reason to think that the ore bodies do not continue? A. No, we have no proof with the exception of the Evans, of any ore body that has been bottomed.

Q. And your opinion is that it does continue? A. Undoubtedly.

Q. I understand the Evans is the only one you can put in that class? A. We are not prepared to say, we are not satisfied that such is the case. We are of the opinion that it is faulted, but we have not definitely proven it.

DR. MILLER: And it has not been worked for quite a number of years? A. It has not been worked for a number of years, no.

Q. Nowadays there is lots of ore available without it? A. Yes, and at the time the Evans was worked the geology of the district was not as well known as it is now.

[1] See also Mr Miles' evidence in Section H, The Canadian Copper Company, and Section N, Taxation of Mines.

Concentration of Low Grade Ores

Q. Of course, in estimating your reserves at present, you are considering ores which do not need to be concentrated, but if, in the future, you wish to concentrate, you will have much larger reserves? A. Yes, the concentrating ores have been omitted from all our estimates.

MR. GIBSON: You say sixty-five to seventy million tons in your opinion would be a fair estimate of the probable ore, using the word "probable" in the sense in which you defined it. What would you regard as ore and not ore? A. Three per cent. total metals or over.

Q. As ore? A. Yes.

Q. Less than that you would not class as ore? A. No.

Q. That is to say, in your opinion, you cannot make a profit out of less than 3 per cent. ore? A. I would not say that, but I would say that with the methods now in use we would not work an ore under 3 per cent. I don't mean to say a 3 per cent. ore in the ground, but sorted to 3 per cent. in the rockhouse.

Q. If you had a mass of ore in the ground that contained 3 per cent. metallic contents, would you regard that as worth anything? A. Oh, yes.

Q. In the ordinary way of handling, that would become higher grade ore? A. Yes; on the other hand, you may have a deposit that would average only 2 per cent., but with the rock mixed with it in such a way that it would lend itself to separation by the method which we use now, and by sorting it you could bring it up to 3 per cent. I included all such ore in that estimate.

Q. Well, then, in what case would ore containing not more than 3 per cent. not be valuable? A. If you take a deposit such as the Frood, the mineral is scattered through it in such a way that it would have to be separated mechanically, and it does not lend itself readily to hand-picking. In other words, the ore is mixed with rock throughout, but as all of the rock is mineralized, it is very difficult to separate it by hand.

Q. Take the Frood ore; if the Frood deposit had been less than 3 per cent. would you have regarded it as a valuable mine? A. Yes, I would, but not as mines are worked now.

Q. I mean with the present methods of treatment? A. No, I would consider it a concentrating proposition.

Q. Would that opinion be based upon the fact that that ore is not easily workable; you do not want to be bothered with it, you mean? A. Yes. It will not be necessary to work those ores for a good many years to come, but I daresay by the time we are ready to work them, methods will have been developed which will enable us to work them at about the same cost.

Q. What is your view with regard to the prospect of assistance from flotation methods? A. We have done no real work in flotation outside of a little laboratory experimenting, and for that reason I am not in a position to say. Mr. Corless has done, and I think has very successfully done, flotation. We have not done it, for the simple reason that it has not been necessary.

Q. You have plenty of ore to handle, so at present you do not require to use these methods. Flotation methods have been successfully adapted to the treatment of copper ores in the West; would they have any bearing on your problem? A. Yes, I think they would. I cannot say from actual operating experience. To my mind there is no doubt that flotation would be adaptable.

CHAIRMAN: In regard to getting rid of silica, are there any prospects of coming across large and reasonably cheap deposits of limestone that would help you along? A. Not very close at hand. There are limestone deposits on Manitoulin Island, that are a mixture of calcite and magnesite, which could be used. I think that is the nearest limestone to the mine.

Q. I suppose from your point of view, for the moment anyway, there would be no special advantage in "selective" flotation, getting twice as much nickel in one product as in another, and then smelting them separately? It would not pay under your present system of working? A. I cannot say, but you have not solved the problem of separation. You have only partially done so, and you have not simplified your methods of refining in any way.

Q. Then your view would be that selective flotation would only be valuable if you tacked on some additional process or modified your present process? A. Yes, otherwise you would have too many products to deal with.

Q. It would really mean mixing together what you have already separated, I suppose? A. Yes.

[*A. D. Miles.*]

NICKEL STEEL AND OTHER NICKEL ALLOYS

Evidence of Dr. Walter Rosenhain, London, Eng.

(London, England, 27th March, 1916.)

DR. ROSENHAIN, who is Superintendent of the Department of Metallurgy and Metallurgical Chemistry in the National Physical Laboratory; Member of Council of the Institute of Metals; Past President of the Optical Society of London; Carnegie Medallist of the Iron and Steel Institute; Vice-President of Section A (Metals) of the International Testing Association for New York meeting (1912); Member of International Committee on the Nomenclature of Steel; Chairman of the Nomenclature Committee (Non-ferrous metals) of the Institute of Metals; Member of the International Juries of Awards (Metallurgy Section) for the Exhibitions at Brussels and Turin; Author of "An Introduction to the Study of Physical Metallurgy" (London—Constable and Company, Limited), attended on the Commission and gave evidence as follows:—

Properties of Nickel Steel

CHAIRMAN: One of the things we wanted information on was the advantages of nickel steel for structural work, automobile parts and so on, and the prospects of its increased use for such purposes? A. I do not know whether you have seen the new standard specifications issued by the Engineering Standards Committee on automobile steels? The Engineering Standards Committee has recently prepared, and I think is now issuing, a report containing the standard specifications of a number of steels which are recommended for automobile use. Incidentally, they will serve—that is not officially stated, but it is a fact—also for air-craft use. Among those are a certain number of nickel steels; in fact all the alloy steels included are nickel steels or nickel-chrome steels. To that extent the use of nickel steel for automobile purposes and for air-craft purposes is already standard practice. The amount of nickel used in them is of course relatively small.

Q. I suppose about 3½ per cent. of nickel is common? A. Three per cent. to 5 per cent.

Q. And is it a fact that if you get over 4 per cent. up to a certain limit which I do not know, those steels are inferior, and then when you reach a higher percentage of nickel they again become valuable, much as is the case with manganese steels? A. Yes; broadly speaking there is a similarity between nickel steels and manganese steels. It does not do to carry the analogy too far, but there is a very considerable similarity. But the whole knowledge of these things is not as perfect as it ought to be, and anything I say about it is largely subject to correction on further investigation. The best knowledge on the subject available to me at the present time is this, that up to a certain limit the nickel steels are very similar to the carbon steels in their properties, but rather better. One difficulty is that when you get any considerable proportion of nickel, certainly when you begin to get over 6 per cent., they are apt to harden during cooling, even when the cooling is not very rapid. When you increase the nickel still further they are normally hard even when slowly cooled, and cannot be softened by any reasonable treatment. When, however, you increase the nickel again to a further considerable amount you get another type of steel which is soft when quenched, and in some cases does not even need quenching; it is soft when cooled in the ordinary way. But some of those have a very extraordinary property; in the soft condition they are extraordinarily strong and ductile, but they harden up under work in the most remarkable way. In the Seventh Report of the Alloys Research Committee there is a description of a steel which contains about 25 per cent. of nickel which to the file is quite soft. It would bend, and generally draw and work quite easily at first. If you try to cut it with a saw, the first few strokes of the saw are quite easy; then the next stroke breaks the saw; the steel hardens up. Really, that is an inversion of the steel into the other type, into the hard, brittle, intermediate type under the influence of work. Then when you go a little higher still in nickel content you come to a class of steel containing about 37 per cent. of nickel, which has very remarkable properties. The best known of these steels is known as "Invar," which is an iron-nickel alloy containing as little carbon as possible; it has an extremely low co-efficient of expansion within the range of about 0° C. to 80° C.; its expansion is less than that of any other known metal. It is so little that Invar is used for the pendulums of standard clocks in order to avoid the effect of temperature on the rate of the clock, and its use is also advocated for standard measures, survey tapes, and things of that kind.

[*W. Rosenhain.*]

Q. I believe it is also a fact that its expansion can be made practically what is wished, so that it can be used for the leading-in wires for glass? A. Yes. Guillaume, of Paris, has worked a great deal on those lines with it, and it is used for a good many purposes besides merely sealing into glass. It is used for the correction of chronometer balance wheels, both for making springs, and for the wheels themselves, so that the change of elasticity with the temperature, and the expansion of the wheel which alters its moment of inertia, are balanced. You can make comparatively cheap clocks which are extraordinarily good time-keepers. The quantity of steel used for that purpose is of course very minute. The torsion pendulum clocks, the 300-day clocks, were practically impossible because of the temperature effects, until the use of these steels came in. I may refer you to a little article I wrote in *Nature* a couple of years ago on the use of nickel steels in clock-making.

Q. I want to ask you as to the effect of carbon and sulphur in nickel steels as compared with their effect in others, and particularly in the presence of copper. I have been told that sulphur is much more injurious in the presence of copper in nickel steel than it is when copper is not there, but I do not know whether that is so? A. That is a matter for investigation. I do not think it is known. The general question of the larger utilization of nickel steel for structural purposes, that is to say not for small parts of machines but for large things such as bridges, roofs, and ships, is entirely a question of expense. At present the cost of nickel makes it prohibitive for such uses.

Q. There is no doubt about its advantage if it can be got? A. I think there is no doubt whatever that if you could get nickel steel for a price which would compare commercially with the ordinary carbon steels, it would be distinctly advantageous to use it, because its mechanical properties are better, and I think that its corrosion properties are probably better.

Q. Is it as easily worked as an ordinary carbon steel? A. Not altogether, no.

Q. I mean the low nickel steel? A. Yes, I know—the 3 per cent. That is a point upon which I should advise you to gather the opinion and the experience of the actual steel maker.

Q. Have you any knowledge of those low nickel steels such as the Mayari steel made from Cuban ore, and containing, say from 1 to 1¼ per cent. of nickel, which are what may be called natural nickel steels, sold for special purposes and said to be extremely good as they stand, but which require the addition of further nickel to bring them up to the ordinary nickel steels? A. I have no real knowledge of those.

Natural Mixtures vs. Artificial Alloys

Q. From your experience of alloys, would you agree with many makers that, if you can take a natural mixed oxide and reduce it to a metal, you get a more homogeneous alloy than if you mix two metals and make the alloy in that way? A. I should feel disposed, if I were speaking to you as to the board of a company dealing with these things and who wanted to make a homogeneous metal and to sell it for the highest price, to advise you to tell the public that as it is made from the natural ore it is therefore more homogeneous. But if you want the best metal, make it out of the pure metals and mix them. I do not think there is any question whatever that the homogeneity of the finished product can be equally secured, or rather can be secured with certainty, if you mix the pure metals; and it cannot be secured with such certainty if you use the mixed oxides and reduce them. The reason is this, and I think this will appeal to you at once, that two oxides are never equally reducible. There is always a difference in the temperature, or in the general reducing conditions required, as, for instance, between nickel and copper. If you have the two oxides mixed in a reduction furnace, it follows, as the temperature conditions differ, or as the proportion of carbon or carbonic oxide gas present in different regions of the furnace differs, you will actually get a more quantitative reduction of one oxide and a less quantitative reduction of the other, and therefore, you will be just as liable to get uneven composition as you would if you mixed the metals and did not stir them sufficiently. Added to that there is this, that mixed oxides being always natural products are apt to vary in composition; in fact, they do vary in composition. I do not think anyone has ever yet discovered a lode in which the mixture of oxides was uniform right through. Consequently, unless you have the most stringent analytical control in making the alloy you will get variations. Now, to say that there is really any difference in homogeneity in a properly made alloy compounded of the pure metals or made in the other way, I think is absolutely wrong. Liquid metals are so easily soluble in one another that the order in which they are introduced, or the form in which they are introduced, is quite immaterial. I can give you an interesting historical example of that. For a very long time brass was always made by the reduction of a mixed ore, a zinc-copper ore; it was called calamine brass. In spite of the fact that those ores are still available if they are wanted, that method has been entirely superseded by the exact mixing of carefully weighed quantities of the pure metals. If anyone wanted to make the best varieties of brass at the present day by reducing mixed oxides he would be two hundred years behind the times.

[*W. Rosenhain.*]

MR. YOUNG: Have you made any experiments along those lines? A. Not actual experiments on reducing mixed ores. I should regard it rather as a waste of time to do so.

MR. GIBSON: But where you get a natural ore, such as those of which Mr. Holloway speaks, would you think it feasible to make a good metal? A. I should expect that it would be necessary to reduce the ore into ingot form and then re-mix and re-melt in order to get uniform results. I should not anticipate getting direct from the ore a commercially uniform material. I do not mean that the different parts of one ingot would be any less uniform than when made the other way, but from one ingot to another—from one cast to another, rather—there would be likely to be greater variations than we would admit in a modern engineering specification.

Q. Could uniformity be secured by careful mixing when making the steel? A. Yes, that could be done, but it would require careful analytical control. If you do that—if you apply sufficiently thorough analytical control, then any of these things is perfectly feasible. That is to say, if you have to deal with a mixed ore there is no difficulty in doing it, but it does mean a very thorough control. You have to keep on analyzing your ore, analyzing your melt and making additions all the time.

Q. I quite understand that what you say will be correct if a very uniform result is necessary or desirable; but if it is not so, if there is a variation allowable in the result, then the ores might be smelted direct? A. They might be smelted direct in any case, but I take it you are now speaking of steel production, and that would not be direct from the ore, I take it. You would first of all reduce the ore to a form of pig?

CHAIRMAN: Yes; that is what they do with the Cuban ore. A. And then you re-melt the pig, or run it straight into a mixer?

Q. They use the open-hearth at Maryland, and they slag off the bulk of the chromium. But they did not speak to me of having had any difficulty in getting a uniform product. I think that is mainly due to the fact that the original ore is so remarkably uniform? That is so, I think, Mr. Gibson?

MR. GIBSON: The ore is not uniform; the more highly nickeliferous ores are found in the bottom strata.

CHAIRMAN: But it is worked in a way which gives them a pretty uniform product?

MR. GIBSON: Yes.

THE WITNESS: The ore is reduced in the blast furnace?

CHAIRMAN: Yes. A. And then it is pigged? Is it allowed to solidify?

Q. Yes. A. Then you have easy control, because you can analyze your pig and mix up batches; then it is all right. After all, as a commercial proposition, it would be no easier to control than with your nickel and your iron separate. The question of degree of uniformity which is necessary in a product depends entirely on what you are going to use it for. With the very light nickel steels, 2½ to 3 per cent., I imagine small variations in the nickel content are not very important.

Q. When you come to 3 or 3½ per cent. it is more important? A. If you go higher than 4 or 5 per cent. it depends on the carbon content, but a small variation in the nickel percentage may give you hard spots due to local cooling, and things of that kind.

Q. I suppose that those remarks you have made with regard to the disadvantage of using what we call natural mixtures refer to all alloys, whether steel or otherwise? A. Yes, I think so. I was speaking of alloys generally.

Q. What is your opinion as to the use of nickel in special aluminium alloys, such as are used for aeroplanes? Is it used to any large extent in making those light alloys? A. No, it is not, and I think the prospects are altogether against it. I should not advocate the use of aluminium nickel alloys. They have been investigated by Rheod and Greaves, and the result has been described in a paper read before the Institute of Metals in 1914. The adverse results they found I can confirm from my own experience. We are now practically excluding nickel from light alloys.

Q. Roughly speaking, we could say all light alloys are unimportant to us? A. Yes, I think so. There was one concern floated to deal with aluminium-nickel alloys commercially which has just been liquidated.

Projected Research Work in Nickel Alloys

Q. When we met you the other day at the National Physical Laboratory, you told us you had made a suggestion regarding certain research work in connection with nickel steel; could you tell us what that suggestion was, on what lines, to whom it was made, and whether anything has been settled? A. Nothing has been settled yet. The suggestion was one of a number regarding researches which the Laboratory was putting forward for the consideration of the Privy Council Advisory Committee. That is the Committee under Sir William McCormick, which is sometimes called the Industrial Research Council. The suggestion was made based on the following ideas: that fundamental to the further development of the special steel industry, that is to say the industry of alloy steels, what is urgently required is a more intimate knowledge of the nature and constitution, the chemical and physical properties, of the alloys of iron and carbon, in the first place with nickel, and also with other elements,

chromium, vanadium, etc., either with nickel or without it. The reason for suggesting a research of that kind was that in advising the air-craft constructors, particularly in the use of steels for their engine parts, and also in dealing with nickel steels and nickel-chrome steels used for military and ordinary purposes, we have frequently had cases of failure sent to us to examine, which in nearly every case, after considerable study and experiment, we have proved to be due to wrong treatment. Sometimes the steel chosen was not of the right composition. In one instance the nickel was too high and the carbon too low; in some cases the quenching temperature had been wrongly chosen; and in other cases, the tempering had been uneven, and so forth. All that points to the fact that even the best of steel makers do not base their practice on a sufficiently sound foundation of real knowledge; and when we come to investigate these matters, we find that we ourselves do not possess a really sufficient basis of sound knowledge, simply because these things have never been investigated carefully and exhaustively enough. Consequently, in dealing with cases of this kind, we have to make something like a research on each particular steel as it comes to us. Quite recently, we have found that the microscopic study of these alloys particularly puts in our hands an extremely powerful weapon for diagnosing cases of wrong treatment, and this method is now actually being used in most important contracts as a means of settling whether the heat treatment of certain forgings was right or wrong. We put forward the idea that in order to place our knowledge of these things on a better basis—not only the knowledge of the Laboratory and its staff, but of the industry generally—a thorough, systematic and scientific investigation of the whole question of the nature and constitution and properties of these alloys is required. That, of course, is a very large piece of work, and to be done in any reasonable time it will have to be undertaken with considerable means; it will mean having three or four people working at it the whole time, with the necessary apparatus and materials.

Q. Would that include the question of nickel steels containing copper, either deliberately added or present because it was originally in the ore? I ask, because in the Canadian nickel ores, as you know, there is a large proportion of copper, and the ore can be selected so that we have a great preponderance of nickel, or any proportion practically that is wanted. There are statements, which seem to be pretty well founded, that the copper present in the nickel within certain limits is advantageous rather than otherwise; or at any rate, the copper will more or less replace the nickel and save money even if it were added deliberately, and considerably more so, if it is originally present in the ore? A The question of the study of the nickel-copper steels was not included in the programme as I mapped it out, because the question had not arisen—I was not aware of it till you mentioned it—to any considerable extent. I had heard of the use of copper in American ingot iron.

Q. It is said to resist corrosion and to increase the tensile strength? A. Before you can consider nickel-copper steels, you must first know about nickel steels. It is impossible to say whether the presence of copper is an advantage or otherwise, until you know what the steel ought to do in the presence of copper.

MR. YOUNG: Are the prospects of getting that carried out reasonably good? A. I think so.

Q. When would the work be completed? A. The completion would probably be a matter of two or three years, but we should hope to publish the results as they came in.

Q. Would those results be available for the use of the Commission? A. I have no doubt they would be, at any rate on application to the Privy Council Advisory Committee.

Q. Do you think interim reports might be handed out from time to time? A. I have no doubt that to any public body like yours they would be made available.

CHAIRMAN: What do you think of the prospects, under normal conditions, of expansion in the use of nickel on present lines and of the probability of new uses being found? A. It is extraordinarily difficult to predict what the possible uses and expansion of a thing are likely to be. I think myself that nickel-copper alloys are not used as fully as they might be. There is room for a great deal of work on those.

Q. That would include Monel metal? A. Yes. Of course the real reason that has retarded the use of nickel is the cost.

MR. YOUNG: What is the limit of prohibitive cost?- A. I cannot say; I do not recollect. I think possibly there are electrical uses of nickel which have not been exploited.

CHAIRMAN: Of course they are using large and increasing quantities now for hydrogenating oils? A. Yes.

Q. Have you any experience or knowledge of the advantage of cobalt for making high speed steels? A. No, not at present.

Q. The Germans make what they call iridium steel, and the Americans make stellite? A. I have heard them, particularly iridium steel, spoken favourably of; and steel makers generally, judging from their conversation, appear to me to have some idea that cobalt is going to be very important. But I have no actual knowledge.

Blast Furnace vs. Electric Furnace

Q. With regard to electrical furnace work, if current can be got at say $15 per horse power year, as it can be at Niagara and a good many other places in Canada, how do you think it would compare with ordinary direct blast furnace practice, considering that the products are

very valuable, and that you get more uniformity in working, and better control? A. Do you mean actual smelting from the ore, or refining?

Q. Smelting from rich ores, and, in the case of nickel, from roasted ores? A. I am afraid I am not an expert on that point, and I would rather not offer an opinion. My general impression is that electric furnace smelting has not yet proved itself, so far as I am aware, anywhere in steel. Whether it would prove itself for nickel steels, or for nickel ores, I do not know. My own impression so far has always been—but it is only an impression—that electrical refining furnaces are a commercial proposition if the product is valuable enough; but the electrical reduction furnace, that is to say the so-called electric blast furnace, has not yet reached the commercial stage. The point is that in a smelting furnace reduction by carbon is such an extraordinarily efficient thing, that it is extremely difficult for electric furnaces to compete. The electric furnace gains over the ordinary smelting furnace by the fact that in it the heat is generated *in situ* in the material which you are treating; but in a reduction furnace, a blast furnace for instance, you generate your heat by the combustion of your charge just as efficiently as you can possibly do it electrically, and of course at much lower prime cost. Where you have to bring in your heat from outside by a gas flame or some other means of that sort, if you generate the heat in the metal you are gaining in efficiency in that way, but in the blast furnace you are not.

Q. I think we have asked the only questions we had to put to you, but probably you will be able to think of a good many things to tell us that I have not asked you? A. May I ask you a few questions? Perhaps that will lead to results.

Why Not Apply Carbonyl Method to Ore Direct?

Q. Yes; we shall be very glad. A. For instance, what is your position with regard to the carbonyl method?

Q. We have not yet visited the Mond Company's refinery in Wales, but, as you know, they smelt ore in Canada to a matte containing 80 per cent. of nickel plus copper and about 20 per cent. of sulphur and very little iron. Both the International and the Mond produce that kind of matte, which is refined by the former in the States, and by the latter in Wales. A. What I was wondering was whether it would pay you to try and get the process worked in Canada?

Q. That is one of the things we have to consider, of course. A. It seems to me that the smelting into a matte, concentrating in fact, is simply done to save the cost of carriage and transport. It might be possible to apply the process without so much preliminary treatment of the rich ore if you did not mind the cost of carriage.

Q. Without smelting it down to 80 per cent. matte to begin with? A. Yes.

Q. That I would not like to say. A. It is worth consideration.

Q. The practice of both companies is, and has been for a very long time, to bring it down to 80 per cent., and it is an interesting thing that the New Caledonia people, who have no copper and who smelt oxidized ores instead of sulphide ores, adopt a very similar practice. A. But they have to send it away, too.

Q. Yes; they send it away in the form of a comparatively rich matte. A. That is done in nearly all metallurgical processes, like the zinc concentrates from Broken Hill; they are concentrated just simply to save carriage.

Influence of Carbon on Nickel

Q. You think that is the main reason? A. I think that is the main reason There are two other points which occur to me. Have you gone into the question of the influence of carbon on nickel?

Q. No. That was one of the questions I asked you A. Carbon on metallic nickel, not on nickel steels. You know pure nickel is used for certain purposes. For instance, if you want to draw it into wire, I believe that a comparatively small amount of carbon in it will render it brittle. The carbon in nickel does not behave like carbon in iron and form anything equivalent to a steel. It is thrown out of solution as a graphite in the nickel, and renders it brittle and short. Not only that; I believe if nickel containing carbon is used for making alloys, like the alloy which used to be called German silver, carbon spoils it, so that the production of nickel free from carbon for alloying purposes is very important; and keeping the alloys free from carbon during the process of manufacture is also important.

Q. Of course now they melt a very large amount of the nickel and granulate it, and sell it in that form as well as in ingots. The cube nickel is sold to a smaller extent than it used to be but contains less carbon than formerly. A. Yes. If you are trying to develop the uses of nickel, as I understand you are, all these are points which will repay study, because those are the things which cause difficulties in the use of it. There are two or three possible uses of nickel which have occurred to me just now, and of course the cost has been the great trouble there. I have used nickel very successfully for furnace implements, because they do not burn away anything like so fast as when made of iron—I am speaking of hooks and rakes, for instance, the rakes used in raking slags, and all that kind of thing.

[*W. Rosenhain.*]

MR. YOUNG: Would that amount to much commercially? A. It might amount to quite a good deal. It would be pure nickel. It would not be nickel-steel containing 3 per cent.

CHAIRMAN: The cost would be very heavy, would it not? A. Yes, the cost is fairly heavy, but for certain purposes where it is important to avoid contamination of your charge, the less oxidizable nickel is very useful. Then, of course, there is another use of nickel which is attaining considerable dimensions; that is its electrical use as resistance wires. I am speaking of the alloy known as "nichrome"

Q. What is the proportion of nickel and chromium in that? A. I think there is roughly about 40 per cent. of nickel.

Q. And "constantan" has nickel in it? A. Yes.

MR. GIBSON: The nichrome alloy is used in electric heaters? A Yes. We use it a great deal in our laboratory furnaces. It is being made in this country now.

CHAIRMAN: Wiggin makes it. A. Yes; Wiggins are the people. You should get in touch with Mr. Boeddicker. He is an extremely able man and knows the business. All these things which I have been mentioning to you, German silver, etc., are largely derived from his experience.

MR. YOUNG: Is not there an English equivalent for constantan? A "Eureka."

CHAIRMAN: Yes Constantan is its Continental name, but it is commonly used everywhere.

MR. GIBSON: What is it used for? A. Electrical resistances. It does not change its resistance very much with temperature. It has a very high resistance and a very low temperature co-efficient. Manganin and platinoid are others.

CHAIRMAN: The Americans make a considerable amount? A. Driver Harris' wires are made of that; they brought out nichrome. They have a Manchester agency and stock in this country.

Q. Would the presence of chromium up to 2 per cent., say, in iron ore containing 0.75 per cent. to 1 per cent. of nickel, be objectionable in making steel? A. I think you would have to get rid of it, up to that percentage, but I do not think this would be difficult. You can stand up to 1 per cent. of chromium in a nickel chrome steel—3½ per cent. of nickel and 0.75 per cent. to 1 per cent. of chromium.

Q. What advantage does the chromium give up to these limits in the nickel steel? A. I think the steel with the chromium in it is distinctly stronger than the nickel steel by itself.

Q. That does not mean a reduction in the amount of nickel, but an improvement in the quality by adding the chromium? A. Yes, that is it, that is one of the points—what is exactly the best composition.

Investigating Standard Automobile Steels

Q. And that would come within the research that you were suggesting? A. Yes. There is a Committee at work, a Joint Committee of the Institution of Automobile Engineers and the Society of Motor Manufacturers and Traders, which has on it representatives of the War Office, the Admiralty, and the Air Service; it is receiving a grant, I believe from the Privy Council Committee for carrying out an investigation on the standard automobile steels, that is to say, the steels which have been included by the Engineering Standards Committee in their Standards Specification of steel for automobile construction. There are ten steels altogether, and I think they are investigating them in two compositions each, the lower and higher limit of each specification. But, of course, that is not a theoretical investigation at all, it is solely to establish the specifications for those steels more accurately, to find the influence of heat treatment, the ordinary variations of composition, the influence of the size of piece on the effect, and matters of that kind.

MR. GIBSON: Is that investigation being made at the National Physical Laboratory? A. It is being made to a large extent at the National Physical Laboratory; but the way they put it is this: in order to see what are the likely variations as between the standard reached at the National Physical Laboratory and the kind of thing that is done in private establishments, they are having the work duplicated and in some cases triplicated; that is to say, in addition to being done at the National Physical Laboratory it is being done by private investigators, such as Mr. Brearley and Mr. Brayshaw. They have divided it up so that each kind of test is going to be done by at least two people, of whom the National Physical Laboratory is nearly always one—it is in all cases where we could undertake the work—the purpose being to see how far competent workers would disagree among themselves owing to the natural variability of the materials, the limits of accuracy of the instruments used, and so on. It is largely with a view to seeing what can be insisted upon in a specification.

Q. The results of an investigation of that kind will be available only to those persons who are making it, I suppose? A. I am not sure what is going to be done. I imagine it will be published ultimately. At any rate, the results will be embodied in the Engineering Standards specification at the end. You see, you specify a certain analysis; you write down what you think the limits ought to be within which the steel must lie. That kind of thing is fairly arbitrary, unless you really know what is the effect of exceeding those limits. That is the kind of knowledge we want. You say what the heat treatment ought to be, quenching at, say, 820°

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followed by tempering at 400°. What we want to find out is, does it matter whether you quench at 820 or 830—does it matter whether you temper at 400 or 420? I am merely giving those figures as rough indications of the kind of thing. You see the importance from the practical point of view. And also, if you specify tempering at 400, and three different people do it, assuming the National Physical Laboratory result is accurate—that the temperature used there is the standard temperature—how near will other people working with ordinary appliances get to that standard. Cobalt is regarded as a dangerous impurity in the nickel for certain purposes.

CHAIRMAN: In steels? A. No, not in steels, in nickel plating. That is one of the things which is strenuously tested for in all nickel plating in connection with high explosive shells. It is a curious fact that, although nickel forms no dangerous compound with certain of these high explosives, cobalt does.

MR. GIBSON: Have any experiments been made with the use of cobalt as a plating agent here in England? A. I have seen some account of it. I have never seen any actual cobalt plating, but the accounts I have read are very promising. I have been working now for nearly ten years on aluminium and its alloys, and the results achieved in the production of new alloys and materials with properties which were practically undreamed of before are quite astonishing. I think if similar work were done on nickel and its alloys you would probably arrive at materials which were extremely interesting and important.

CHAIRMAN: That which you have told us about the nickel steels becoming extraordinarily hard under working is very interesting. A. That has been known for a good many years, I think. It was published in 1905.

Q. Does that same steel, if it is hammered, get harder and harder? A. Yes, it gets very brittle in the cold after a few blows; at a higher temperature it softens again. The magnetic properties of nickel steels are very interesting, too. That steel becomes magnetic on working. It is not magnetic when it starts.

Q. I forget whether you told us how much nickel that contained? A. I think about 25 per cent.

MR. GIBSON: What are the uses of a nickel steel containing so large a percentage of nickel? A. Except for the purpose of Invar, that is specially low expansion alloys, I do not think it has any use at present.

Q. What percentage of nickel do they use for heavy ordnance—those large guns? A. The information I have on that is confidential; but it is not high.

CHAIRMAN: I Suppose, roughly speaking, we could say that nickel steels on a big commercial scale would average somewhere under 5 per cent? A. There are some which are used as high as 8 per cent. for special purposes.

Q. I meant the average all round? A. The great majority of nickel steels contain between 3 and 4 per cent. of nickel—certainly under 5 per cent. There was a very curious set of phenomena which occurred with the earlier nickel steels, namely, spontaneous disintegration. With regard to certain grades of nickel steel in the early days one could never be sure whether they were going to be very good material, or whether one would find a heap of powder. What was the real cause, I do not think has ever been thoroughly investigated.

Q. Would that have any connection with the so-called "diseases" such as occur with tin occasionally? A. I do not know whether there was a sort of allotropic transformation. I have never come across the phenomenon, and it has never been fully investigated. With regard to a great many of these things which you hear about, when you come to make accurate investigations, you find they do not occur.

Special Uses for Nickel

Q. It would almost look as though it was due to some impurity through careless working in the olden times? A. Here is another thing—steam turbine blading. Nickel steel, I believe, was attempted for that for a long time I believe it has been largely given up now, as there was trouble with the nickel steels. But that question is worth looking into, as nickel steels are still used by some makers of steam turbines. It is a very important matter, as a very large tonnage of turbine blading is used.

Q. That is, for the internal parts of the turbine engine? A. Yes, the vanes.

Q. Of course that is a very big thing? A. Yes. A great many of them are being made of brass now.

Q. They have gone back to the old system then? A. Yes. I should imagine that possibly some form of nickel-copper alloy or nickel-copper-aluminium alloy might be very useful for that.

Q. How do the nickel-copper-aluminium alloys compare with ordinary nickel-copper alloys? A. I believe that at that end of the scale, that is to say the bronzes consisting largely of copper, nickel is useful as an addition to aluminium-copper. With regard to the light alloys I condemned it, as you know. But at the other end, I believe there is a range of utility. The trouble is that those alloys are so tremendously strong that a great many of the people who are accustomed to dealing with non-ferrous alloys have not got the plant to handle them.

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Q. That would refer to those containing from 8 to 10 per cent. of aluminium, for instance? A. Something of that order, yes—say 7 per cent. of aluminium and 3 per cent. of nickel.

MR. YOUNG: Would it be possible to get statistics of the output of nickel steel in this country? A. I think you might get it from the Iron and Steel Institute if you ask them. Locomotive boiler tubes is another possibility for nickel steels, possibly even for pure nickel. Of course there the expense is the trouble. Still, as you are down to one shilling sixpence per pound now under present conditions, I should imagine the price ought to go down a good deal lower than that.

Q. It has not gone up so much as one would have expected? A. No.

MR. GIBSON: Has nickel ever been tried here for steel rails? A. Yes, I believe so, but I think the expense has stood in the way there. Experiments have been made. I remember having a steel rail containing nickel for examination. I certainly suggested it to one of the railway companies myself some years ago. I am not quite sure now whether they tried it or not.

CHAIRMAN: They have used it a good deal in the States. In one case where the rails had stood well for a long time, they had to take them out because they had to do something to the line so that the test was never properly finished, but the evidence seems to be in favour of it. A. Yes. I should imagine at any rate that in tunnels it would be useful.

Q. It was in a tunnel on the Pennsylvania railway.

MR. YOUNG: The cost of the nickel is a factor there, obviously? A. Yes, it must be, although as the intensity of railway traffic increases and axle loads and speeds get higher, the resistance to wear of a rail is more important than its prime cost, because the labour of frequent renewal comes in.

Q. I suppose the same principle would apply to boiler tubes and the other matters you have mentioned? A. Yes. I will tell you another possibility for the special use of nickel. Non-corrodible alloys are wanted very badly in connection with such work as the sinking of artesian wells in Australia. That was a problem that was put to me when I was out there, and I was quite unable to give a solution. The waters in Queensland are very highly saline hot waters, and ordinary iron tube corrodes rapidly. They have to be made hundreds of feet deep. They are simply tubular bores, and great streams of hot water gush out. These tubes disappear in the course of a few months. One could afford to go to a very considerable cost for a tube in order to give it a longer life. I should imagine that very possibly one of these alloys might be found that would answer the purpose.

CHAIRMAN: The sellers of Monel metal have issued some very interesting pamphlets on the use of their metal? A. I know. Of course the high speed steamship propeller is another problem. I think the future of the thing lies in finding the uses, if you want to dispose of a large output.

[W. Rosenhain.]

SECTION D

PRODUCTION OF NICKEL-COPPER STEEL FROM SUDBURY ORE

By Alfred Stansfield, D.Sc., A.R.S.M., F.R.S.C., Professor of Metallurgy, McGill University, Montreal

[NOTE.—This paper, and the two immediately succeeding, also by Dr Stansfield, deal respectively with (1) the general subject of the production of nickel-copper steel from the ores of the Sudbury district, (2) experiments by himself in the actual production of such material under a patented process, and (3) the use of the electric furnace for smelting the ore]

During the year 1914 one million tons of nickel-copper ore was mined and smelted in the Sudbury district of Ontario. From this was produced 47,000 tons of bessemer matte containing 22,700 tons of nickel, and 14,400 tons of copper. Some 400,000 tons of iron, equal to half the Canadian production of pig iron, was slagged in the furnace and thrown over the dumps, and 300,000 tons of sulphur was discharged into the atmosphere.

The producing companies control the situation and make a good profit by the present practice; but it is worth while considering whether the 400,000 tons of iron and 300,000 tons of sulphur cannot be utilized, thus stopping a serious drain on Canadian resources.

Utilization of Iron Content

Attempts have been made to obtain the iron, which forms 40 per cent. of the Sudbury ores, by re-smelting the slags or waste products left after the separation from the ore of the nickel and copper. Such an operation may perhaps be profitable, but as 70 per cent. of the nickel that is produced must be alloyed with iron for the production of nickel steel, there is no need to separate the nickel from the iron in the first place, and it should be far more profitable to smelt them together for the production of nickel steel.

The production of nickel steel from the Sudbury ores has not been carried out in the past, partly because it was not possible to remove the sulphur so completely that the roasted ore could be smelted to pig iron, and partly because there was too large a proportion of copper in the ore to permit of its conversion into steel, and the excess of copper could not economically be separated.

In recent years improvements in roasting and desulphurizing methods have overcome the first difficulty; and further, it has been found that a moderate proportion of copper is not harmful in nickel or steel, so that a large proportion of the Sudbury ores can now be worked up into a nickel-copper steel having properties substantially the same as those of the standard nickel steel. In this way the iron contained in the ore will be recovered in the form of nickel steel, and incidentally the sulphur of the ore can be recovered as sulphuric acid or sulphur dioxide for use in chemical industries.

To desulphurize the ore it would be crushed to a powder and roasted in a mechanical furnace of the Wedge type, enabling the sulphur to be recovered, and doing away with the nuisance of the roast heaps. The roasted ore would then be put through a nodulizing kiln, thus reducing the residual sulphur to a very low figure, and leaving the ore in nodules suitable for blast furnace smelting. A pig metal would then be obtained having nickel and copper contents about double that of the original ore, and this pig metal would be worked up into steel by the usual methods, enough scrap iron or steel being added to reduce the nickel and copper to suitable proportions.

An alternative method would involve the use of the electric furnace for making the pig metal. The ore could be roasted in mechanical furnaces to a few tenths of one per cent. of sulphur, and then smelted electrically to a pig metal; the electric smelting process would serve to remove the residual sulphur, and the electric furnace would be less dependent than the blast furnace on receiving the ore in a lumpy condition.

Copper as an Ingredient of Steel

Until a few years ago it was supposed that copper was a harmful ingredient in steel, but recent experiments have demonstrated that a moderate addition of copper imparts valuable properties to steel. Work has also been done, on a commercial scale, on the production of nickel-copper steel. This has been made by adding Monel metal to ordinary steel in the open hearth or electric furnace, and it has been ascertained that if the combined nickel plus copper amounts to 3½ per cent., and if the copper is somewhat less than one-half of the nickel, the steel obtained is substantially the same in mechanical and other properties as the regular 3½ per cent. nickel steel. It should be possible to select a large amount of ore having

[*A. Stansfield*]

copper contents as low as one-third the nickel contents, and the remainder of the ore, which would be relatively high in copper, could be worked up, as at present, by methods involving the separation of copper and nickel, and the production of these metals in the pure state.

The electric furnace would be employed for smelting the roasted ores which might still retain some tenths of one per cent. of sulphur, for the production of a pig metal having only a few hundredths of a per cent. of that element. Electric furnaces might also be used for making the nickel steel, or more probably for finishing the steel which has been made in the Bessemer converter, or open hearth furnace.

The Objects to be Achieved

The proposal outlined above includes these separate propositions:—

1. The production of nickel-copper steel from the Sudbury ore; thus avoiding the separation of the nickel from the copper.

2. The production of a nickel-copper steel from the Sudbury ore, without the separation of the iron; thus avoiding expense of this separation, and gaining the iron as a part of the resulting steel.

3. Desulphurizing the ore in mechanical roasting furnaces instead of by heap roasting; blast furnace smelting and Bessemer converting, thus getting a more perfect roast at a smaller cost, and saving the sulphur gases for use in chemical industries.

4. Turning the roasted ore into a pig metal by one of the following processes:—

(a) By agglomeration of the roasted ore (to eliminate sulphur and make the ore lumpy), followed by smelting with coke in a blast furnace.

(b) By smelting (probably with charcoal) in an electric furnace.

5. Turning the resulting pig metal into a nickel-copper steel in the open hearth furnace or Bessemer converter, possibly followed by electric furnace treatment to obtain the highest quality of steel.

If we admit that it is desirable to produce a nickel-copper steel, the following general questions remain for consideration:—

1. Whether to treat the original ore by the new process, thus avoiding the heap roasting, blast furnace smelting and possibly the bessemerization stages of the present process, or to start with the furnace matte or even the bessemer matte, thus having a proportionately smaller amount of the material to handle.

2. Whether to convert the roasted ore in the pig metal by desulphurizing agglomeration followed by smelting in the blast furnace, or by means of the electric furnace.

Suggestions for Procedure

The following considerations which have a bearing on these questions and on the whole problem may be presented:—

(1) One short ton of Sudbury ore may be assumed to contain the following amounts and values:—[1]

——	Per cent.	2,000 lbs.	Price[2]	Value
				$ c.
Copper	1.2	30 lbs.	at 10 cents.	3 00
Nickel	3.5	70 "	" 30 "	21 00
Iron	40	800 "	" 0.5 "	4 00
Sulphur	30	600 "	" 0.5 "	3 00
Silver	....	0.2 oz.	" 50 "	10
Gold	....	0.01 "	" $20	20
Platinum	....	0.01 "	" $40	40

The present proposal aims at saving the $4.00 worth of iron and $3.00 worth of sulphur, but would waste the 70 cents' worth of precious metals at present recovered. There will be a saving of $5.00 (per ton of ore) through the substitution of some 25 lbs. of copper for the same weight of nickel in the finished steel, and a further saving of perhaps $4.00 by the more perfect recovery of the metals nickel and copper, through the avoidance of the present mechanical and leaching losses in heap roasting, and slag losses in the blast furnace smelting.

(2) The preliminary crushing of the ore would be carried out at or near the mines, and would be combined with mechanical ore dressing operations for removing the gangue and rock matter more perfectly than is now found necessary or desirable.

[1] The ore smelted for treatment by the proposed process would contain rather less copper, in relation to the nickel, than is shown here. The percentage of these metals and of the iron and sulphur would all be raised somewhat on account of the elimination of the bulk of the gangue and rock matter.

[2] The prices assigned to the metals have been set below the regular market price, so as to represent roughly the value of the crude metal extracted from the ore.

[A. *Stansfield*]

(3) The roasting, smelting to pig metal, and final production of the nickel-copper steel would all be carried out at some centre such as Sault Ste. Marie, where fuel and power are abundant, where the sulphur gases could be utilized, and where iron smelting and steelmaking are already in operation.

(4) With reference to the alternative proposals to start with the raw ore or with the furnace matte, it may be stated in a general way that the value of the iron and sulphur gases obtained by the first alternative should about meet the cost of roasting and smelting the ore for pig metal, so that on the whole it would appear preferable to use the ore instead of the matte as the starting point. A pig metal obtained by the treatment of the matte would be more valuable per ton of product, and would therefore stand transportation charges better; but if the roasting, smelting and steel-making could all be conducted at the same point, this argument would have little weight. The present proposal will entail the haulage of the whole weight of the dressed ore from the mine to some point such as Sault Ste. Marie, at which the later operations can be carried out profitably, but it must be remembered that some 90 per cent. of the ore would be valuable material whether nickel, copper, iron, or sulphur, as the gangue matter should easily be kept down to about 10 per cent.

Conclusion

It was originally intended that this memorandum should deal with "the application of electric smelting and electric furnace methods to the treatment of nickel and nickel-copper ores and furnace products for the production of nickel steel, nickel-copper steel and similar alloys," but it soon became evident that the electric smelting was subsidiary to some general scheme for the utilization of the ores. Electric smelting of the roasted ore or the roasted matte, and electric furnace production of steel can readily be fitted in when the general scheme has been decided on.

18th January, 1916.

EXPERIMENTS IN MAKING NICKEL-COPPER STEEL

By Dr. Stansfield, Montreal

(1) The Process to be Investigated

This is " a process of manufacturing iron alloys " described in the United States patent No. 1,106,785 of August 11th, 1914, granted to George M. Colvocoresses, of New York, N.Y.

The process is employed for the treatment of sulphide ores containing the metals nickel, copper and iron, such as the ores found in the Sudbury district in Ontario; the ores being selected however so that the copper in the ore shall be small in relation to the nickel, examples cited showing a ratio between these metals of from 2.5 to 4.

The ores are first crushed to a fine powder, preferably to pass a 20-mesh sieve, and the crushed ore is roasted in a mechanical roasting furnace, such as the Wedge furnace, until the sulphur has been reduced to about 1 per cent.

The roasted ore is then smelted to a cupro-nickel pig iron, either by smelting it (in the powdery condition) with a limestone flux (and charcoal or other reducing reagents not mentioned in the patent) in an electric shaft furnace, or by nodulizing the (powdery) ore with lime or other binder and smelting with coke, limestone, etc., in a blast furnace.

The resulting cupro-nickel pig iron is made into steel in an electric furnace, open-hearth furnace, or Bessemer converter, with the addition of as much iron as may be needed to reduce the proportion of nickel and copper to the desired extent.

Comparing this process with the usual treatment of the Sudbury ores for the production of nickel steel, it will be seen that in this process the nickel, copper and iron, originally present in the ores, are all smelted and reduced together, and all enter the resulting steel, while by the present method the iron is separated and lost, and the nickel and copper are separated and purified, and the nickel so obtained is again alloyed with iron for the production of nickel steel. The product obtained differs however in the two cases, because by the new process the copper as well as the nickel found in the ore, will enter the steel.

(2) Discussion and Investigation of the Process

The value of the process will be seen to depend on the following points:—

(a) Whether a steel containing nickel and copper in the proportions already indicated is as valuable as a nickel steel that is free from copper.

(b) Whether the process discloses efficient and economical methods for producing a nickel-copper steel from the Sudbury ores.

(c) Whether steel produced by this process is actually as good as nickel steel made by the usual processes.

[*A. Stansfield.*]

(a) The Properties of Cupro-Nickel Steels

It was supposed at one time that copper was injurious to steel, causing red shortness, but during recent years a large number of tests have been made which show that this idea is incorrect, and that copper has, for many purposes, a beneficial effect on steel; at any rate when present in amounts less than one per cent. Reference may be made to a paper by G. Howell Clevenger and B. Ray, on "The Influence of Copper upon the Physical Properties of Steel," Trans. Amer. Inst. Min. Eng., XLVII (1913), p. 523. Copper resembles nickel in its effect on steel, as it increases the elastic limit without decreasing the ductility of the metal, and in small additions it renders steel less liable to corrosion.

Copper is only slightly soluble in steel, and segregation becomes noticeable when the copper exceeds 0.75 per cent. but in combination with nickel this defect is not produced, as nickel combines freely with iron and also with copper, thus tending to produce a uniform alloy. Cupro-nickel steels have been made in recent years, not only experimentally but for commercial purposes, by the addition of Monel metal (nickel 70 per cent., copper 28 per cent., iron 2 per cent.) to ordinary steel. A steel to which 3½ or 4 per cent. of Monel metal has been added is found to resemble in mechanical and anti-corroding properties a 3½ or 4 per cent. nickel steel. Reference may be made to a paper by G. H. Clamer on "Cupro-nickel Steel," Proc. Amer. Soc. for Testing Materials, X, 1910, p. 267, and to the discussion of this paper by J. A. Mathews, p. 274.

G. H. Clamer (Iron Trades Review, LI, 1912, p. 931, and Jour. Iron & Steel Inst., LXXXVII, 1913, p. 671), describes cupro-nickel steel produced from Monel metal, or from the Sudbury bessemer matte by roasting it and reducing the oxides to metal. He says that copper acts so much like nickel when present in the proportion of 2.5 per cent. of nickel to 1 per cent. of copper, that it is possible to produce a nickel steel of practically the same physical properties as nickel steel at a very much reduced cost.

It would no doubt require far more elaborate tests than have yet been made to establish the equality or superiority of cupro-nickel steel, as compared with nickel steel, in regard to all the uses to which the latter is put, but there appears to be enough evidence to show that a cupro-nickel steel in which the copper is not more than about one-third of the nickel, resembles an equivalent nickel steel so closely that it can be expected, on account of its smaller cost, to replace the latter to a considerable extent when its properties have been more fully tested.

(b) Detailed Discussion of the Process

The process described in the patent appears in general to be an efficient and economical method for producing a cupro-nickel steel from the Sudbury ores, and should be decidedly cheaper than the existing method of making nickel steel by the addition of metallic nickel to steel, or of making a cupro-nickel steel by means of Monel metal. The several steps will now be considered in detail:—

1. *Crushing and Roasting:*—The test described later shows that the sulphur can be reduced to below 1 per cent. without great trouble, and without the very fine crushing referred to in the patent. I consider that the crushing could be carried out by means of rolls, reducing the ore to about one-tenth inch, and thus avoiding the production of a large amount of very fine powder.

The roasting could be carried out economically in mechanical furnaces of the Wedge type, fuel being needed in the later stages of the operation. From an economic point of view, it would seem very desirable to utilize the SO_2 gases for the production of sulphuric acid or other sulphur products, in view of the enormous amount of sulphur now being wasted in the Sudbury district.

2. *Smelting to Pig Metal:*—This operation serves to convert the oxides of nickel, copper and iron into the metallic form, to remove the gangue matter as a slag, and also to remove the remaining sulphur so that a pure pig metal shall be produced for steelmaking.

In view of the need of crushing the ore before roasting, it will be possible to submit the ore to a preliminary dressing operation for the removal of the bulk of the rock matter. As however a certain amount of slag will be needed to carry off the sulphur, this dressing operation must not be carried too far.

Smelting the roasted ore in an electric shaft furnace is a satisfactory means of removing the remaining sulphur and obtaining a pig metal, but it seems probable that some briquetting process should first be used in view of the finely divided nature of the roasted ore. For electric smelting it is usual to employ charcoal as a reducing reagent: the amount needed in Sweden being about 40 per cent. of the weight of the resulting pig metal. The amount of charcoal used in the test described later was about 70 per cent. of the weight of the pig, but there was a very large loss by dusting. It will be safe to assume the production of two tons of pig metal per year for each horse power supplied to the furnace, and a consumption of charcoal equal to 55 per cent. of the metal produced. Reference may be made to the following papers dealing with electric smelting:—

Eugene Haanel, Ph.D.: Report on the Experiments made at Sault Ste. Marie, Ont., under Government Auspices in the Smelting of Canadian Iron Ores by the Electrothermic Process, Ottawa, 1907.

In run No. 18 (p. 79 of the Report) a roasted pyrrhotite from the Sudbury district was smelted with charcoal and limestone. The roasted ore contained 2.23 per cent. of nickel, 0.41 per cent. of copper, 45.8 per cent. of iron and 1.56 per cent. of sulphur. The charge finally employed consisted of 400 lbs. of ore, 105 lbs. of charcoal and 40 lbs. of limestone, and the resulting pig metal contained 4.1 per cent. of nickel, 0.7 per cent. of copper, 0.006 per cent. of sulphur and 0.04 per cent. of phosphorus. In all 14,500 lbs. of ore was smelted, and 7,336 lbs. of pig metal was produced. The power consumption was 0.39 E H.P. year per 2,000 lbs. of pig metal, and the charcoal used was 55 per cent. of the weight of metal obtained. The ore had been crushed to a fine powder and roasted in mechanical furnaces for the production of sulphur gases, and the roasted ore was briquetted with lime before being smelted.

On page 93 of the Report there is given an account of the commercial smelting of this ore under the direction of Mr. E. J. Sjöstedt; about 168 tons of cupro-nickel pig iron being produced at the rate of 1.34 tons per day.

The average requirements for 2,000 lbs. of this pig metal were:

Roasted ore (about 2 per cent. sulphur)	4,000 lbs.
Limestone	1,500 lbs.
Charcoal (60 bushels at 20 lbs.)	1,200 lbs.
Electrodes	40 lbs.
Electrical horse-power years	0.46

The pig metal contained 4 per cent. nickel, 0.8 per cent. copper, 0.01 per cent. sulphur and 0.03 per cent. phosphorus.

Some earlier work of Mr. Sjöstedt is reported in a paper on "Electric Smelting Experiments for the Manufacture of Ferro-Nickel from Pyrrhotite," Trans. Amer. Electrochem. Soc., Vol. V, 1904, p. 233.

A report by myself on "The Electrothermic Smelting of Iron Ores in Sweden," Ottawa, 1915, contains a very careful investigation of the commercial smelting of iron ores in Sweden, and should be studied by anyone undertaking the commercial smelting of iron ores. The results contained in the report are, however, not directly applicable to the treatment of Sudbury ores, because the Swedish ores are almost entirely free from sulphur, and because, in a simple shaft furnace such as would be employed for their treatment, the consumption of charcoal and of electrical power would both be higher than in the elaborate and costly furnaces in use in Sweden.

For operating on a moderate scale, electric smelting may be the most satisfactory, but if a large scale operation is contemplated it would no doubt be more economical to employ the blast furnace. The roasted ore would be fed, with the necessary addition of tar, into a nodulizing kiln which would serve to remove the sulphur and produce nodules suitable for the blast furnace. A recent account of this process is given in the Mining and Engineering World, 1915, XLII, p. 415, and Journ. Iron & Steel Inst., XCI, 1915, p. 497. The smelting operation would then resemble ordinary iron ore smelting, using coke or charcoal according to the requirements of the steel-making process.

3. *Refining the Pig Metal to Make Steel:*—The pig metal produced by smelting Sudbury ores will contain about 5 per cent. of combined nickel and copper, and for the production of cupro-nickel steel of about 3½ per cent. of these metals it will be necessary to add steel scrap (or pig iron) equal to about 50 per cent. (or less) of the weight of the cupro-nickel pig. On account of the large proportion of pig metal to be treated, the process of steelmaking by the open-hearth or electric refining furnace would be somewhat slow and costly, as was found in the test described later, and the most economical method would probably be to blow the pig metal to steel in the Bessemer converter, and to transfer the blown metal to an open-hearth, or preferably to an electric furnace, for finishing. The ore is so low in phosphorus that it would not be necessary to use basic lined furnaces, but electric furnaces usually have a basic lining.

(c) Steel Made from Sudbury Ores

In preceding sections it has been indicated that a cupro-nickel steel may be expected to compare favourably with a nickel steel of similar composition, and that the process described appears in general to be suitable for the production of a cupro-nickel steel from the Sudbury ores. It remains to be seen whether we have direct evidence of the quality of steel that has actually been made from these ores.

For this purpose we may discuss the published results of tests that have been made in the past, and also the test that has now been carried out at McGill University, which is described in detail in the following section.

[*A. Stansfield.*]

Dr. J. A. Mathews (loc. cit.) describes an experiment made by the Halcomb Steel Company in producing a cupro-nickel steel in their Heroult electric furnace from the cupro-nickel pig iron produced at Sault Ste. Marie from Sudbury ores. The steel was compared mechanically with a nickel steel made by the usual process in the open-hearth furnace, and the results obtained were as follows:—

Chemical Analysis

	O.H. Nickel, per cent.	Cupro-nickel, per cent.
Nickel	3.36	3.62
Copper	....	0.48
Carbon	0.46	0.44
Manganese	0.70	0.50
Sulphur	0.034	0.013
Phosphorus	0.021	0.013
Silicon	0.066	0.034

Tensile Test as Rolled

	O.H. Nickel.	Cupro-nickel.
Elastic limit, lbs. per sq. in.	74,625	72,400
Tensile strength, lbs. per sq. in.	122,000	115,000
Elongation in 2 ins., per cent.	16	22
Reduction in area, per cent.	34	51

Tensile Test Annealed

Elastic limit, lbs. per sq. in.	64,750	63,750
Tensile strength, lbs. per sq. in.	119,000	107,300
Elongation in 2 ins., per cent.	17	25
Reduction in area, per cent.	37.5	48

Quenched in Oil from 1500°F. and Reheated to 800°F.

Elastic limit, lbs. per sq. in.	154,500	154,000
Tensile strength, lbs. per sq. in.	175,000	172,500
Elongation in 2 ins., per cent.	9.75	13.25
Reduction in area, per cent.	30.8	49.1

These results indicate a distinct superiority for the cupro-nickel steel as compared with the ordinary nickel steel, and while this may perhaps be due in part to the fact that the cupro-nickel steel was made in the electric furnace while the nickel steel was made in the open-hearth furnace, we can accept it as conclusive evidence that a very high quality steel, equal in mechanical tests to a standard nickel steel, has been produced from the Sudbury ores by the methods described in the patent.

The steel produced at McGill University was not nearly as good as that made and tested by Dr. Mathews, and therefore cannot serve as absolute proof in this connection. If, however, we consider the difficulties involved in making steel in the laboratory, the results obtained are perhaps as good as might be expected, as they tend to confirm our belief that a high quality of steel can be made by this process.

(3) Experimental Test of the Process

Some Sudbury ore weighing 480 lbs. was selected by Mr. H. A. Morin and shipped to Montreal, arriving in the University on Saturday, the 8th January.

The ore was crushed and sampled, being reduced until it all passed through a screen having one-tenth inch diameter round holes. This crushing is coarser than was recommended in the patent specification, but was found to be fine enough.

The ore was analyzed and found to contain:—Ni 3.06 per cent., Cu 0.25 per cent., Fe 53.09 per cent., S 33.80 per cent., SiO_2 6.65 per cent.

The crushed ore, weighing 458 lbs., was roasted in a hand-rabbled reverberatory furnace on Monday the 10th January from 9 a.m. to 7 p.m., and on Tuesday the 11th from 9 a.m. to 9.30 p.m., the total time of effective roasting being about 20 hours. After the first day the sulphur was reduced to about 2 per cent. and after the second day to about 0.5 per cent. The temperature on the second day was raised to about 750°C. About one ton of coal and the

[*A. Stansfield.*]

labour of one man for two days was used for this operation, but this is of no practical importance, as the costs would be very much less under commercial conditions. The analysis of the roasted ore showed:—

Ni 4.064 per cent., Cu 0.225 per cent., S 0.479 per cent. The weight of roasted ore was 370 lbs. There is a little discrepancy between the ratio of nickel to copper in the raw and the roasted ore, but this was not serious enough to warrant any additional work to clear it up.

The roasted ore was next smelted in a small electric shaft furnace. The furnace was 9 inches by 13 inches in internal dimensions, and about 18 inches high. It was built of fire bricks, and the bottom had a lining composed of burnt magnesite and pitch rammed in while hot and baked in position. Two vertical electrodes were used, each of one and one-half inch round Acheson graphite. The electrodes were about 6 inches apart, centres, and were kept low in the furnace so as to concentrate the heat near the hearth, being raised or lowered as required. The furnace had been built for some other experiments, and did not work as well as our usual arrangement, in which the bottom lining is of coke and pitch with an electrode imbedded in it, so that all the electric current passes from the movable electrodes to the bottom of the furnace. Additional tests will be made later with the furnace rebuilt in this way. The ore was mixed with crushed charcoal and limestone in the proportion of 20 lbs. of ore to 5 lbs. each of charcoal and limestone.

The first smelting operation was made on Thursday, the 15th of January. A charge consisting of 40 lbs. of ore with 10 lbs. of charcoal and 10 lbs. of limestone was smelted in two hours, using 20 K.W. of electrical power. The metal tapped weighed 16 lbs., and contained about 7.11 per cent. nickel, 0.60 per cent. copper, 0.37 per cent. sulphur, and 0.14 per cent. carbon. It was evident from the appearance of the metal that there was a deficiency of carbon in the charge, this being caused by the charcoal dust blowing out of the furnace, and the proportion of charcoal was therefore increased. A charge of 40 lbs. of ore, 14 lbs. of charcoal and 10 lbs. of limestone was smelted in 1 hour and 40 minutes, using 22 K.W. The metal tapped weighed 18 lbs., and contained 4.47 per cent. Ni, 0.30 per cent. Cu, 0 074 per cent. S. 0.75 per cent. C. The power consumption was about two and one-half K.W. hours per pound of metal for the first charge, and about 2 K.W. hours for the second charge.

The next smelting operation was carried out on Saturday, the 15th January, using the second charge mentioned above, but with the addition of molasses and water to reduce the loss by dusting; the charge being dried before charging into the electric furnace. The first charge consisted of 40 lbs. of ore, 14 lbs. of charcoal and 10 lbs. of limestone with 3 lbs. of molasses. Two such charges were smelted in two and one-half hours, using about 22 K.W. and yielding 40 lbs. of metal, which contained 5.08 per cent. Ni, 0.40 per cent. Cu, 0.15 per cent. S, 2.68 per cent. C. The power consumption was 1.4 K.W. hours per pound of metal Two more charges each of 40 lbs. ore, 14 lbs. charcoal, 2 lbs. carbon, 15 lbs. limestone and 3 lbs. molasses were smelted in 2 hours 45 minutes, using about 22 K.W. and yielding 39 pounds of metal containing about 4.8 per cent. Ni, 0.35 per cent. Cu, 0 018 per cent. S, 3.3 per cent. C. This shows a power consumption of 1.5 K.W. hours per pound of metal, but some metal remained in the furnace at the end of the run.

The two smelting operations described above show that the roasted ore can be smelted electrically to produce a nickel-copper-ferro pig metal low enough in sulphur for conversion into steel. As, however, most of the metal produced in these tests was too high in sulphur, it was remelted under a limey slag until the sulphur was reduced to about 0 05 per cent. This remelting and necessary repairs to the furnace occupied most of the following week; a little additional ore being smelted at the same time.

The pig metal so produced was made into steel in a tilting acid-lined arc furnace on Saturday the 22nd of January. The furnace will hold 100 lbs. or more of steel, but as it was desired to make at least two distinct heats, the metal on hand was divided so as to make two heats of about 60 lbs. each.

The first heat consisted of 47 lbs. of pig metal and 16 lbs of mild steel scrap. The pig metal contained 4.60 per cent. Ni, 0.30 per cent. Cu, 0.045 per cent. S, and 3 per cent. carbon. The charge was melted in about 40 minutes, using 22 K.W., after which three hours were spent in bringing the carbon down by additions of iron ore. Ferro-silicon, ferro-manganese and a little aluminum were then added in the furnace, and the steel was poured into iron moulds 2½ x 2½ x 12 inches. The steel was sound, but the ingots were rough as some slag entered the moulds. The steel was found to contain 3.45 per cent. Ni, 0.27 per cent. Cu, 0.43 per cent C, 0.27 per cent Mn, 0.05 per cent. S, 0.040 per cent P. The weight of ingots obtained was 50 lbs.

The second heat consisted of 43 lbs. of pig metal, 9 lbs. of scrap steel and a few pounds of scrap from the last heat. The pig metal contained 4.8 per cent. nickel, 0.37 per cent. copper, 0.07 per cent. sulphur and about 3 per cent. of carbon. The charge was melted in about one and one-quarter hours (using less power than in the first heat), and the carbon was reduced in about three hours more by additions of iron ore and lime. Ferro-silicon and ferro-manganese were added as before, and the steel poured into moulds, giving about 45 lbs. of ingots.

[*A. Stansfield*]

Drillings were taken from the steel ingots and analyzed, showing as follows:—

Nickel	Copper	Carbon	Manganese	Sulphur	Phosphorus	—
3.45	0.27	0.43	0.273	0.054	0.040	No. 1 Steel
3.86	0.30	0.53	0.792	0.061	0.049	No. 2 Steel

Ingots from both heats were drawn down under a hammer into round rods about 1 inch in diameter, and standard test pieces were prepared from these rods and tested in the testing laboratory of the University, with the following results:—

No. 1 Steel	Pounds per Square Inch Elastic limit	Yield point	Maximum load	Elongation, p.c. on 2 ins.	Reduction of area—p.c.
Natural 1A................	43,800	59,200	88,800	16.5	29
Natural 1B................	41,300	59,700	88,400	16.7	26
Annealed 1D................	42,700	57,600	87,600	21.5	33
Oil Tempered 1C	61,500	70,000	100,000	19.5	36
Natural 1E................	43,800	52,000	80,000	26.0	39

No. 2 Steel	Pounds per Square Inch Elastic limit	Yield point	Maximum load	Elongation. p.c. on 2 ins.	Reduction of area—p.c.
Natural 2A................	51,000	86,500	121,000	3.3	5
Natural 2B................	45,800	86,600	126,800	4.5	8
Annealed 2D................	66,700	82,500	119,000	14.5	39
Oil Tempered 2C	84,500	....	....	0.	0
Annealed 2E................	50,500	66,300	110,000	19.	33

The elastic limit was determined by means of an extensometer reading to the 1-100,000th of an inch, and will be somewhat lower than would be obtained with the usual, less sensitive apparatus. In many cases the "elastic limit" in published reports corresponds to the "yield point" given above, which is the load producing an elongation just visible to the eye, or the point at which there is an appreciable drop of the beam of the testing machine.

It will be seen from the tests that the No. 2 steel was worked too cold under the hammer, and needed to be annealed in order to obtain satisfactory ductility; 2D and 2E were annealed at different times, and the former gives somewhat better results. Oil-tempered 1C is a very good steel, but 2C, which was treated with it, was too hard and broke sharply at 84,800 lbs. per square inch without any elongation.

The American Society for Testing Materials, in its 1915 year book, gives the following requirements for structural nickel steel.—

Chemical Composition:—	Per cent.	
Carbon, not over................................	0.45	
Manganese, not over.......	0.70	
Phosphorus, not over	0.05	(for acid steel)
Sulphur, not over................................	0.05	
Nickel, not under................................	3.25	

Tension Tests:—	Eye bars and rollers unannealed	Eye bars and pins annealed
Tensile strength, lbs. per sq. in...........	95,000-110,000	90,000-105,000
Yield point min , lbs. per sq. in...........	55,000	52,000
Elongation in 2 in. min., per cent.	16	20
Reduction of area min., per cent..........	25	35

Considering these requirements in relation to the chemical and mechanical properties of the experimentally made steel, there appears no room for doubt that steel could be made without difficulty by the patented process to meet all the requirements mentioned above.

[*A. Stansfield*]

Additional Notes

In regard to the experimental test it should be noted that the proportion of copper to nickel was unusually low in the ore supplied, so that the resulting steel resembles an ordinary nickel steel in composition.

Before deciding to operate this process commercially, it will, of course, be essential to make a careful analysis of the probable costs in comparison with those of the existing methods, and in addition to compare the cost with that of making cupro-nickel steel, using either the furnace matte or the bessemer matte from the present process as a starting point. I am of the opinion that the ore is the correct starting point of this process; but a full analysis of costs should be made before it will be possible to decide which is the best starting point from a commercial point of view.

I wish to add that I have made no investigation of the validity of the patent.

31st January, 1916.

A Third Trial

Dr. Stansfield furnishes particulars of a third trial of electric smelting of the above material and of the resulting steel as follows:—

The roasted ore employed in the previous experiments contained nickel 4.064[1] per cent., copper 0.225 per cent., sulphur 0.479 per cent.

A quantity of this roasted ore, together with charcoal and limestone, and a certain amount of molasses and water-glass for the purpose of agglomerating the powdered material was smelted on the 31st January, 1916, in an electric furnace, yielding 35 lbs. of pig metal. This contained:—

First tap, 0.024 per cent. of sulphur.
Second tap, 0.030 per cent. of sulphur.
The average, 0.028 per cent. of sulphur and 5.12 per cent. of nickel plus copper.

On the 7th February, 1916, the 35 lbs. of pig metal, together with 3 lbs. of a previous pig metal containing 0.016 per cent. of sulphur and 15 lbs. of mild steel scrap, were treated in a silica lined electric furnace for the production of a nickel-copper steel. The products were:—

An ingot of ..	19½ lbs.
A part ingot of	13½ lbs.
Scrap of	9¾ lbs.
Total	42¾ lbs.

The steel contained:—

Carbon	0.38 per cent.
Manganese	0.56 per cent.
Silicon	0.33 per cent.
Copper plus nickel	3.70 per cent.

The ingots were hammered out into bars and tested, but were found to possess very poor mechanical property It was recognized that this must be due to the temperature of casting, or some other defect in the melting of the steel. Accordingly, on the 20th April 12 lbs. of steel were remelted in a crucible and cast into an ingot. The product was found to contain 0.25 per cent. of carbon, but was not otherwise analyzed. The ingot was hammered into a bar marked S.T.4, and a test piece was cut from the lower end of the bar and tested with the following results on the 12th May:—

Elastic limit	70,100 lbs. per sq. in.
Yield point	77,400 lbs. per sq. in.
Maximum load	101,500 lbs. per sq. in.
Elongation in 2 inches	18 per cent.
Reduction in area	31.9 per cent.

Tests at School of Mining, Kingston

Tests of samples of copper-nickel steel received from Dr. Eugene Haanel, Director of Mines, Ottawa, in 1913, made by Dr. H. T. Kalmus, at the School of Mining, Kingston, are given in the Summary Report of the Mines' Branch, Department of Mines, for 1913, pp. 17 to 20. These are quoted below for purposes of comparison.

[1] I am inclined to think that this should be about 3 per cent —A. S

[*A. Stansfield.*]

ANALYSES [1]

	Sample I. Per cent.	Sample II. Per cent.	Sample III. Per cent.
Nickel	2.52	1.69	1.00
Copper	1.01	0.66	0.43
Sulphur	0.042	0.041	0.045
Carbon	0.453	0.43	0.45
Iron	95.95	97.13	98.10
	99.97	99.95	100.02

HARDNESS TESTS

One face of each of these bars, which were approximately 1 inch square in section and 4 inches in length, was smoothed off, and hardness tests made with a Standard Olsen hardness testing machine.

Hardness was computed in the Brinell system. For comparison, the following table of hardness in the same system is given, as measured at this laboratory, under conditions identical with those for the measurements on the copper-nickel steel.

REFERENCE TABLE OF BRINELL HARDNESS

Copper, rolled sheet	65.6	Mild steel	109.9
Swedish iron	90.7	Tool steel	153.8
Wrought iron	92.0	Spring steel	160.3
Cast iron	97.8	Self-hardening tool steel	180.0

BRINELL HARDNESS OF COPPER-NICKEL STEEL SAMPLES

Sample No. I. Brinell Hardness: 166.

This is the mean of 13 independent observations, with an average deviation from the mean of about 3 per cent.

Sample No. II. Brinell Hardness: 149.

This is the mean of 9 independent observations, with an average deviation from the mean of about 3 per cent.

Sample No. III. Brinell Hardness: 139

This is the mean of 9 independent observations, with an average deviation from the mean of about 2 per cent.

TURNING PROPERTIES

Sample No. I.

This alloy machines freely with a medium long curling chip, having the general turning characteristics of a good quality of machinery steel.

Sample No. II.

This alloy machines freely with a medium long curling chip, and is slightly softer and slightly tougher than sample No. I.

Sample No. III.

This alloy machines freely with a very long curling chip, and is distinctly tougher than either sample Nos. I and II.

TENSILE STRENGTH TESTS

Standard 2″ test bars were turned, of about 4″ over all length The heads were threaded, and the effective diameter was ½″.

Tensile strength measurements were made on a Universal Standard Riehle Testing Machine.

Sample.	Maximum Tensile Stress	Elastic Limit.	Contraction of Area.	Elongation on 2″ specimen.	Fracture.
			Per cent.	Per cent.	
No. I	110,000 lbs./in.²	76 500 lbs./in.²	33.2	20	Crystalline.
No. II	91 800 "	61.200 "	47.0	28	Finely granular.
No. III	85,700 "	61,000 "	42.4	25	Very finely granular

FORGING QUALITIES

Sufficient material was not supplied to make a careful study of the relative forging qualities of these three samples, but a single experiment with the pieces resulting from the tensile strength measurements showed that all three samples forged with the greatest facility.

[1] These analyses are, in each case, the result of duplicate check determinations

[*A. Stansfield*]

PRODUCTION OF NICKEL AND NICKEL ALLOYS IN THE ELECTRIC FURNACE

By Dr. Stansfield, Montreal

[NOTE—This paper was prepared in response to a request from the Commission, and should be considered as an addition to Dr. Stansfield's memorandum dated 18th January, 1916 See page 38

(A) Electric Smelting of Nickel Oxide

In view of the ease with which nickel oxide can be reduced to good commercial nickel, there can be no serious difficulty in smelting the oxide, with the addition of charcoal, in an electric furnace; but it might be desirable first, to briquette the oxide either alone or in combination with the charcoal. As the oxide is nearly free from sulphur, there will be no need to use limestone in the charge beyond the small amount needed to flux the charcoal ash.

The process will vary according to the kind of nickel required. (1) For nickel in granules or ingots for use in steel making, it will not be necessary to limit the carbon contents very closely, and the nickel need not be free from oxide or dissolved gases. Such a metal can be obtained at once by smelting the oxide with a moderate excess of charcoal in a simple electric shaft furnace such as that used by Dr. Haanel at Sault Ste. Marie. (2) If for any reason the carbon is required to be very low, say under 0.5 per cent., this product can probably be obtained directly by smelting the oxide with a limited amount of charcoal. (3) For very strict requirements as to carbon, or if any oxidizing refining is necessary, the pig metal can be transferred to an electric arc furnace and then finished with the aid of oxidizing fluxes. (4) For the production of sound nickel castings, it will be necessary to add magnesium or other deoxidizer to the molten metal before casting it into moulds. This addition can probably be made in the ladle.

For smelting a comparatively small amount of a valuable material like nickel oxide, it will be undesirable to construct and use an expensive and elaborate furnace like the Elektrometall iron smelting furnace described in my report on the electrothermic smelting of iron ores in Sweden. A simple shaft furnace can be used, having a carbon-lined hearth, serving as one electrode, or a hearth of magnesite or similar material. The latter type will be the best for the production of a carbon-free metal. With electric power at $15 per E.H.P.-year the smelting of nickel oxide in such a furnace should be as economical as by existing methods.

Assuming a furnace of 240 E.H.P. which would produce some 2 tons of nickel per 24 hours, the following may be given as the approximate requirements of the operation:—

(1) Electrical Power

An estimate of the thermal requirements of smelting nickel oxide shows that one ton of nickel would need about 60 per cent. of the heat required to make one ton of pig iron from an average magnetite ore. Applying this to the results set out in my Swedish report, it appears that we can count on the production of three long tons of nickel per year for each electrical horse power allotted to the furnace.[1] The electrical power will therefore cost $5.00 per long ton of nickel produced, or, as the nickel will be about 80 per cent. of the oxide, $3.60 per short ton of oxide treated.

(2) Charcoal

The amount of charcoal or other reducing reagent needed to reduce an oxide to the metallic state depends largely upon the reaction that takes place. Nickel oxide is reduced very readily by means of carbon monoxide, and we might expect that the reaction would be $2NiO+C = CO_2+2Ni$. Judging, however, by the behaviour of electric iron-smelting furnaces, it appears safer to assume that the equation $NiO+C = CO+Ni$ represents the reaction that would take place in an electric furnace where the oxide is projected, with little time for preparation, into a region of very high temperature. The carbon needed is theoretically 20.5 per cent. of the metal, or 16.1 per cent of the oxide. If the charcoal contains 85 per cent. of fixed carbon, the amount of charcoal needed will be 24 per cent. and 19 per cent. respectively, or with a small allowance for mechanical loss, 25 per cent. of the nickel or 20 per cent. of the oxide treated. If the resulting nickel is carburized, the consumption of charcoal will be about 29 per cent. and 23 per cent. respectively.

[1] The calculation is made, in the first place, per long ton of metal produced instead of per short ton of the material smelted, so that the figures can be compared readily with the data given in my report on the electrothermic smelting of iron ores in Sweden The charge made for electrical power is not based on the amount of energy actually delivered to the furnace, but on the maximum power the furnace is permitted to draw from the high voltage supply lines. The estimate thus allows for losses in transformation, stoppages for repairs, and for the fact that the load factor cannot, in regular operation, be kept steadily at 100 per cent., see pages 9 to 12 of my report. In comparing the data given by Dr. Haanel in his report on the electric smelting of iron ores at Sault Ste. Marie, it should be remembered that he estimates pig iron by the short ton, and measures the electrical power actually supplied to the furnace.

[*A. Stansfield.*]

It may be mentioned in this connection that a carbon-free nickel can presumably be obtained by use of a limited amount of charcoal, but that some of the nickel oxide will be lost in the slags. These slags will be small in amount, and can be retained and resmelted to recover the greater part of the nickel contents.

(3) Limestone

A small amount, say 3 per cent., will be needed to flux the charcoal ash.

(4) Electrodes

The consumption may be taken at 25 lbs. per long ton of metal; this figure being a little larger than in the Swedish furnaces or Dr. Haanel's experiments. If a deficiency of charcoal is arranged, so as to produce a low-carbon metal, the electrode losses will probably increase, but this will be offset by the greater ease of smelting nickel oxide as compared with iron ore.

(5) Labour

Two men should be sufficient to attend to a furnace making two tons of nickel per day. Their wages, charging $3.00 for the furnace men and $2.00 for the helper, for an 8-hour shift, would amount to $15.00 a day, or $7 50 per ton of metal. The cost of labour will depend greatly on the scale of operation; thus, for a 4,000 h.p. furnace, smelting iron ores in Canada, the cost has been estimated at $1.20 per ton of metal. For purposes of comparison, we may take an intermediate cost of $3.50 per long ton of metal, equal to $2.50 per ton of oxide.

(6) The remaining items of cost given by Gronwall in his estimate of smelting costs in Canada are: Office and organization, 50 cents; repairs, 60 cents; depreciation, 72 cents; general expenses, etc., about $1.00. These, together with interest charges of $1.00, amount to about $4.00 per long ton of metal, and may be included as a single item for the purpose of comparison.

Cost of Smelting Nickel Oxide

Per long ton of nickel.			Per short ton of oxide.	
Electrical power 0 33 E.H.P. year at	$15 00	$5 00	0.24 E.H.P. year	$3 60
Charcoal, 560 lbs. at	12 00 ton	3 00	400 lbs.	2 15
Limestone, 67 lbs. at	3 00 ton	0 10	48 lbs.	0 07
Electrodes, 25 lbs. at	0 04 lb.	1 00	18 lbs.	0 72
Labour		3 50		2 50
Briquetting the oxide		0 70		0 50
General expenses		4 00		2 86
		$17 30		$12 40

In view of the small amount of information available in regard to the electric smelting of nickel oxide, the above figures can only be depended on in a very general way.

(B) Electric Smelting of Nickel-Copper Converter Matte

In the electric smelting of roasted, partly roasted, or raw nickel-copper converter matte containing say 80 per cent. of nickel plus copper and say 20 per cent. of sulphur with a very little iron, say half a per cent., the object sought is a copper-nickel alloy free from sulphur, while the iron contents may or may not be objectionable, according to the use to which the alloy is to be put. The ratio of copper to nickel in the alloy must also be considered.

The best method, in my opinion, will be to crush the matte to a fine powder, say to pass a sieve of 20 meshes to the linear inch; to roast this in a mechanical roasting furnace of the Wedge type to about 1 per cent. of sulphur; and to smelt the roasted matte, with charcoal, limestone and other fluxes in an electric furnace, for the production of a pig metal, low in sulphur. In order to remove the sulphur it is essential to maintain strongly reducing conditions, and consequently the resulting alloy will contain carbon and all the iron of the original matte. The carbon, and if necessary the iron, can be removed in an electric furnace of the steel-making type, by treating the molten alloy with oxidizing reagents; after which a deoxidizing addition would have to be made before pouring the alloy into moulds.

In the past (Schnabel's Metallurgy, Vol. II, pp. 679 and 691) such matte has been treated as follows:—

1. Roasting the crushed matte in reverberatory furnaces to about one per cent of sulphur.

2. Grinding the roasted matte to a very fine powder and roasting it very carefully, with the addition of saltpetre, for the complete removal of the sulphur.

[*A. Stansfield*]

3. Reducing the nickel-copper oxides to an alloy of these metals by means of charcoal in crucibles or in a shaft furnace.

The proposed process replaces the second and third of these stages by a reducing fusion with fluxes in an electric furnace. This process may now be considered in detail:—

(1) Roasting the Matte

According to the references quoted, the matte, after fine crushing, can be roasted in hand-rabbled furnaces to about one per cent. of sulphur with the use of about five-sixths of its weight in coal. This roasting can be carried out more economically in a mechanical furnace of the Wedge type, and should not need more coal than 25 per cent. of the weight of the matte.

(2) Smelting in the Electric Furnace

Oxides of nickel and copper can without doubt be reduced to an alloy by means of charcoal in an electric smelting furnace. We may also reasonably assume that sulphur can be slagged off in this process, as is the case in the electric smelting of the roasted nickel-copper ore.

We may assume the matte to contain 50 per cent. of nickel, 30 per cent. of copper, 20 per cent. of sulphur and 0.5 per cent. of iron. The roasted matte will have the same weight as the raw matte, and the same percentage amount of nickel, copper and iron. For smelting the roasted matte it will be necessary to add about 22 per cent. of charcoal for reduction, and 30 per cent. of limestone. As there is no siliceous gangue to be fluxed by the limestone, it will be necessary to add a silicious flux (say 15 per cent.) so as to provide a slag to carry the sulphur that was left in the roasted matte.

On account of the need of removing the sulphur, we can only count on producing two tons of metal per H.P.-year (as would be the case in smelting iron ores to pig metal in a simple shaft furnace) and the following table of costs will be arrived at.

Cost of Roasting and Smelting Bessemer Matte

	Per long ton of metal.		Per short ton of matte.
Crushing the matte	$0 70		$0 50
Roasting the matte	3 50		2 50
Briquetting the roasted matte	0 70		0 50
Electrical power, 0.5 H.P. yr. at $15 00	7 50	0.36 H.P. yr.	5 40
Charcoal, 620 lbs.	3 30	440 lbs.	2 36
Limestone, 840 lbs.	1 10	606 lbs.	0 80
Electrodes, 25 lbs. at 4c.	1 00	18 lbs. at 4c.	0 72
Labour (for smelting)	3 50		2 50
General expenses	4 00		2 85
	$25 30		$18 13

It must be remembered that, in view of the limited amount of information available, these figures must be regarded as provisional.

The metal will be an alloy of nickel, copper and iron, corresponding with the proportions of these metals in the matte; it will probably contain some two per cent. of carbon, and should be nearly free from sulphur, say under 0.05 per cent. If the alloy is to be used for the manufacture of a copper-nickel steel, the carbon present will not be harmful, and the alloy can be cast into moulds or granulated for use in this way. For this purpose care would have to be taken in regard to the proportion of copper, which should be less than one-third of the nickel. Alloys containing too large a proportion of copper could be used with an addition of metallic nickel reduced from the oxide as in section (A).

For the manufacture of Monel metal the molten alloy would have to be transferred to a second furnace such as a reverberatory open-hearth, or electric steel-making furnace, where the carbon could be removed by addition of oxidizing reagents. For this purpose air could be blown through the metal, or oxidizing fluxes such as nitre or nickel oxide could be added. After the carbon had been sufficiently removed, a deoxidizing addition such as metallic magnesium would be employed either in the furnace or in the ladle.

(C) Electric Smelting of Blast or Reverberatory Furnace Matte

In the electric smelting of blast or reverberatory furnace matte containing 7 to 10 per cent. of copper, 10 to 17 per cent. of nickel, about 45 per cent. of iron, and about 25 per cent. of sulphur, the material would be treated substantially the same as the bessemer matte already considered. It would be finely crushed, roasted in a mechanical furnace to one per

cent. or less of sulphur, and then smelted in an electric furnace with charcoal, limestone and siliceous flux for the production of a pig metal low in sulphur but containing carbon. This metal could be charged into an open hearth furnace with a suitable proportion of scrap steel for the production of a nickel-copper steel, providing that the ratio of nickel to copper is high enough. If this is not the case, metallic nickel would have to be added to correct the relation between nickel and copper.

Assuming that the matte contain 13.5 per cent. of nickel, 8.5 per cent. of copper, 45 per cent. of iron, and 25 per cent. of sulphur (the mean of the above figures), it will be seen that these figures only add up to 92 per cent. I shall assume that the balance consists of slag or oxides of which no notice need be taken. The roasted matte will weigh the same as the raw matte, and the resulting alloy (apart from losses) will weigh 69 per cent. of the original matte, and will contain 19.6 per cent. of nickel, 12.3 per cent. of copper, 65 per cent. of iron, and 3 per cent. of carbon.

The roasted matte will need for smelting, about 25 per cent. of charcoal, with some 30 per cent. of limestone and 15 per cent. of silicious flux.

The electrical power needed for this operation will be about the same as for smelting iron ore, say ½ E.H.P.-year per long ton of resulting pig metal. The consumption of electrodes may be taken at 25 lbs. per long ton of metal.

Cost of Roasting and Smelting Furnace Matte

	Per long ton of metal.		Per short ton of matte.
Crushing the matte	$0 80		$0 50
Roasting the matte	4 00		2 50
Briquetting the roasted matte	0 80		0 50
Electrical power, 0.5 H.P. yr. at $15.00	7 50	0.31 H.P. yr.	4 70
Charcoal, 800 lbs. at $1.00 per ton	4 30	500 lbs.	2 70
Limestone, 960 lbs. at $3.00 per ton	1 30	600 lbs.	0 80
Electrodes, 25 lbs. at 4c.	1 00	15 lbs.	0 62
Labour	3 50		2 18
General expenses	4 00		2 50
	$27 20		$17 00

In view of the limited amount of information available, this estimate must be regarded as merely provisional.

(D) Electric Smelting of Nickel-Copper Ore

The material to be smelted is nickel-copper ore, containing 4 to 5 per cent. of nickel plus copper and over 30 per cent. of insoluble silicious matter. This ore carries decidedly more silicious matter than is usually found in the ore smelted in the Sudbury region, and it could probably be enriched considerably by hand picking If this were not sufficient, it might be necessary to crush and dress so as to reduce the siliceous matter to some 10 to 15 per cent. of the ore.

We may assume the dressed ore to contain:—3 per cent. of nickel, 2 per cent. of copper, 45 per cent. of iron, 30 per cent. of sulphur, 15 per cent. of silicious matter, and 5 per cent. of basic gangue.

The ore would be crushed to one-tenth inch or smaller, and roasted in a mechanical furnace to 1 per cent. or less of sulphur. My own experiments in a hand-rabbled reverberatory show that such an ore, crushed to pass through one-tenth inch holes, can be roasted to 0.5 per cent. of sulphur in 20 hours. The roasted ore would be 90 per cent. of the raw matte. The crushed and roasted ore would probably require some kind of agglomeration; such as mixing with lime and water, and after drying, would be smelted in an electric furnace with the addition of about 23 per cent. of charcoal and 23 per cent. of limestone, yielding a pig iron low in sulphur (under 0.05 per cent.), containing about 6 per cent. of nickel, 4 per cent. of copper, 87 per cent. of iron, and 3 per cent. of carbon. Apart from losses, the pig metal would be 51.5 per cent. of the dressed ore. The pig metal could be blown in a Bessemer converter to remove the carbon and transferred to an electric furnace, where enough scrap steel would be added to yield the desired percentage of nickel plus copper for a nickel copper steel. For this purpose, however, the ores should be chosen with a smaller percentage of copper, or else metallic nickel or ferro-nickel would have to be added to attain the desired composition.

The electric smelting of the roasted ore would require about ½ E H.P.-year per long ton of pig metal, together with 0.43 per cent. ton each of charcoal and limestone. The labour and electrode charges would be the same as in (C).

[*A. Stansfield*]

Electric Smelting of 1 Net Ton

	A. Nickel Oxide.		B. Converter Matte.		C. Furnace Matte.		D. Copper Nickel Ore.	
Analysis.			Ni Cu S Fe		Ni Cu S Fe		Ni Cu S Fe Gangue	
Raw			50 30 20 0.5		13.5 8.5 25 45		3 2 30 45 20	
Roasted	2,000 lbs. 78 p.c. nickel		2,000 lbs.		2,000 lbs.		1,800 lbs.	
			50 30 1 0.5		13.5 8.5 1 45		3.3 2.2 1 49.5 23	
Metal	1,600 lbs. 99 p.c. nickel		1,600 lbs.		1,400 lbs. C		1,000 lbs. C.	
			61 37 1.5 0.5		19.6 12.3 3 65		6 4 3 87	
Crushing				$0 50		$0 50		$0 25
Roasting				2 50		2 50		2 00
Briquetting		$0 50		0 50		0 50		0 25
Smelting:								
Power	0.24 H.P. Yr.	3 60	0.36 H.P. Yr.	5 40	0.31 H.P. Yr.	4 70	0.22 H.P. Yr.	3 30
Charcoal	400 lbs.	2 15	440 lbs.	2 36	500 lbs.	2 70	430 lbs.	2 30
Limestone	48 lbs.	0 07	600 lbs.	0 80	600 lbs.	0 80	430 lbs.	0 60
Electrodes	18 lbs.	0 72	18 lbs.	0 72	15 lbs.	0 62	11 lbs.	0 45
Labour		2 50		2 50		2 18		1 55
General		2 86		2 85		2 50		1 80
Total		$12 40		$18 13		$17 00		$12 50
Per long ton of metal		$17 30		$25 30		$27 20		$28 10
Per lb. of nickel plus copper		.78c		1.15c.		3.8c.		12.5c.

Cost of Roasting and Smelting Nickel-Copper Ore

	Per long ton of metal.		Per short ton of raw ore.
Crushing the ore	$0 55		$0 25
Roasting the ore	4 50		2 00
Briquetting the roasted ore	0 55		0 25
Electrical power, 0.5 H.P. yr. at $15.00	7 50	0.22 H.P. yr.	3 30
Charcoal, 960 lbs. at $12.00 ton	5 20	430 lbs.	2 30
Limestone, 960 lbs. at $3.00 ton	1 30	430 lbs.	0 60
Electrodes, 25 lbs. at 4c.	1 00	11 lbs.	0 45
Labour	3 50		1 55
General expenses	4 00		1 80
	$28 10		$12 50

The cost of crushing, roasting and briquetting the ore has been assumed to be somewhat lower than in the case of the matte, but all these estimates are merely provisional.

For smelting nickel oxide and bessemer matte, the electric furnace would probably be the best means to adopt in view of the small amount and high value per ton of the material treated; but in the case of the original ore, and possibly even for treating the furnace matte, it seems probable that the blast furnace could be employed with greater economy. For treatment in the blást furnace, the powdered ore must be briquetted or agglomerated, and it is also desirable to have the sulphur more thoroughly removed. These two requirements can both be met by nodulizing the roasted ore with tar in a revolving furnace of the cement kiln type. The nodulized ore, or furnace matte, would then be smelted in the blast furnace in the ordinary way for the nickel-copper pig iron. The pig metal could be transferred to a Bessemer converter, freed from carbon, and worked up into a nickel-copper steel with suitable additions in an open hearth or electric furnace.

The tentative figures arrived at for the cost of smelting in the electric furnace are collected for comparison on the following sheet. In comparing these figures it is, of course, obvious that, per pound of nickel, or nickel plus copper, the Bessemer matte costs less to treat than the furnace matte, and the furnace matte costs less than the ore. These costs would have to be considered in relation to the costs of producing the furnace and Bessemer matte by the present methods. In addition to this, we must take account of the value of the metallic iron obtained by the treatment of the lower grade materials, and of the fact that the losses of nickel and copper will probably be less in the proposed process than in the existing roasting and smelting process. We should also consider the possibility of utilizing, by the new methods, the very large amount of sulphur that is now wasted in the Sudbury region. It has already been pointed out that for the treatment of the ore, and possibly for the furnace matte, a process of roasting, agglomeration and smelting in a blast furnace would be more economical than the electric furnace process.

In your letter of the 12th January it is suggested that the electric smelting might be carried out in the Niagara district. For the smelting of nickel oxide and other high-grade materials this might be a satisfactory location, but for the production of a nickel-copper steel (and sulphuric acid) from the Sudbury ores, it would probably be better to crush and dress at the mine, and to ship the concentrated ore to Sault Ste. Marie for the remaining operations.

At Sault Ste. Marie electric power can be obtained at a moderate cost, in case electric smelting should form part of the process, while coke and other supplies can be readily obtained for blast furnace operation, and there is a steel plant available for the manufacture of nickel steel. The haul from Sudbury to the Soo also is decidedly shorter than to Niagara, and water transport is available for handling the products of the process.

If the production of a nickel-copper steel, containing some 3 per cent. of nickel and 1 per cent. or less of copper, is ultimately adopted on a considerable scale, it will be necessary to select low copper ores for use in this process, and to leave the higher copper ores for treatment by other methods for the production of nickel.

In regard to the type of furnace to use for electric smelting, it has been stated that a simple shaft furnace would be better for small scale operations than an elaborate and costly furnace of the Elektrometall type. Even if large scale operations were contemplated, it would be desirable in the first place to experiment with a simple furnace of moderate size. It would then be possible to determine whether to adopt the Elektrometall or the Californian type of furnace. In making the estimates of cost, it has been assumed that the furnace plant would cost as much as the Swedish plants in relation to the output.

15th February, 1916.

[*A. Stansfield*]

Evidence of Mr. G. M. Colvocoresses, General Manager Consolidated Arizona Smelting Company, Humboldt, Arizona, U.S.A.

(Toronto, 24th January, 1916, Mr. T. F. Sutherland, Chief Inspector of Mines for Ontario, sitting with the Commission.)

DR. MILLER: I suppose the better plan, Mr. Colvocoresses, would be for you to give us an account of your process for making steel direct from Sudbury ore. A. I may begin by saying that the value of ferro-nickel has, of course, been realized for many years. The French Nickel company in New Caledonia made what they called a "font," which was an impure pig of iron and nickel, back in the seventies or eighties; the nickel ore they had contained no copper or sulphur.

Ferro-Nickel from Sudbury Ores

Some years later, in nineteen hundred or thereabouts, the Canadian Government experimental work carried on at Sault Ste. Marie went to show that a ferro-nickel could be made from the Sudbury ores very satisfactorily, and Mr. E. A. Sjostedt, who was metallurgist there, proposed to make this ferro-nickel directly from the Sudbury ores after removing the copper from the ore. I suppose a great many men have experimented with that. At the time of Mr. Sjostedt's death he had some process in mind for removing the copper, and he claimed he would be able to make commercially a valuable nickel steel containing perhaps a very small percentage of copper. The matter stood in that position for several years, because the attempts that were made to separate the copper from the nickel did not succeed. Some of them separated the copper, but the cost was prohibitive. When the copper was not removed, the steel people protested (as they still protest to a large extent), that copper in any kind of steel is very detrimental to it; that it renders it useless, makes it red-short and brittle, and has many disadvantages

The steel that was made at the Sault under Dr. Eugene Haanel's direction, was afterwards utilized in the United States in several ways. He had made perhaps eight or ten tons of pig metal which contained about one-half per cent. of copper that they had not been able to eliminate. That steel was refined in the United States for test purposes, and was found to be comparable to ordinary nickel steel. It had just as good qualities, in fact, if anything, it was a little superior, being electrolytically refined, and very free from impurities.

Nickel-Iron Copper Alloys

Some years later, Prof. Burgess, of the University of Wisconsin, began to experiment with alloys of iron with copper and nickel. Using the pure iron, he alloyed it with pure copper and pure nickel, and made several different ranges of copper-nickel-iron alloys. This was about the first scientific experimentation with nickel and copper combined in a steel of that nature, although from patent records I have found that a man named Martino, in England in 1860 tried to make a ternary alloy of nickel, copper and steel, and did make it after a fashion. I have been interested in this alloy steel matter for some years, off and on, ever since I was in New Caledonia. I have been doing a little experimenting in connection with the manufacture of steel direct from nickel ores, because it always impressed me that not only the New Caledonia ores, but particularly the Sudbury ores, should be treated as iron ore, and that it was the greatest pity in the world to take 45 per cent. of iron out of a ton of ore and throw it all away; and after you had gotten the pure nickel to put it back in an open hearth furnace with some of the iron you get from Michigan or elsewhere, and work that into a steel alloy. You just get back where you started, more particularly with the Sudbury ore. I believed you could go right straight through and treat Sudbury ore as an iron ore; and if you double the amount of iron, nickel, and copper that is contained in it, you get an iron alloy with just about 4½ per cent. of nickel, plus about one per cent. of copper. The question is whether or not that one per cent. of copper is a detriment.

I ran up against some difficulties in starting this work. In the first place there is no question that sulphur is detrimental to steel, and in the old steels which had been made from time to time, accidentally containing copper, there was almost always a certain percentage of sulphur. I found that out, and as far as I could ascertain from analysis the so-called copper steels which had given copper in steel such a bad reputation always contained sulphur. The old English steel-makers from time to time had made some copper steels that were almost always accompanied by a half per cent. or perhaps only a quarter per cent. of sulphur, enough to be detrimental to it. I had to eliminate this sulphur in the ore first of all, and in the experimental work, as of course it will also be done commercially, I took the Sudbury ore and roasted it; I roasted it sweet.

In the Wedge roaster at Copper Cliff at the present time they are roasting their fines down to, I think, about three or four per cent. sulphur. I have seen other ores roasted in a Wedge roaster down to a quarter of one per cent., and it is purely a matter of supplying

[*G. M. Colvocoresses.*]

the necessary fuel to get it just as sweet as you like; you can roast it and re-roast it. As a matter of fact, you don't need to re-roast it; you can get it down to about half of one per cent., which is quite enough to start with if you are going to make this alloy pig.

Then, there are two methods of manufacturing the pig from the roasted ore. The first method is by nodulizing or sintering, and treating the product in exactly the same way that you treat iron ore in a regular blast furnace. Of course, my experiments were carried on in a laboratory and in a small crucible furnace. I worked partly in the laboratory at Columbia University, New York. When I say that it can be done, I am talking theoretically rather than practically, because I cannot tell you positively that it can be done, since I never did it; but I am satisfied, and I think any steel-maker will be satisfied, that the nodulized roasted ore can be treated in a blast furnace exactly the same as iron ore; smelted with coke and limestone to form silicate of lime slag, the result being an alloy pig containing nickel, copper and iron in relatively the same proportions as the ore.

The other method of handling this material is to run the roasted ore, but without sintering, into an electric furnace. I worked with a small electric furnace similar to the Stassano furnace that they use in Italy, and made a very nice alloy pig from the ore. We used coke to reduce the oxides; you could use, probably, charcoal, but I never tried it. They did try charcoal at the Sault, I believe, and it is probably cheaper. I looked into the work which was being done by electric furnaces elsewhere, and got a tabulation of what seemed to be a fair working cost on the basis of regular production.

After you get your alloy pig, you have considerable sulphur left in it, a certain amount of silicon, carbon, and possibly a few other impurities, such as may occur in the ore. It then remains to refine that material; and this refining can be done, unquestionably, in the electric refining furnace. That was the method I used in the laboratory experiments; and it is exactly similar to the method which steel makers are using to-day, to a very large extent, in refining high grade crucible steels.

As to the cost of the refining, the Bethlehem Steel people did a lot of work on some alloy steels, and they figured that it will cost up to \$10 a ton for refining. I think they exaggerated that cost a little bit. It is being done in Europe to-day as low as \$6, and with the cheap electric power you have in certain districts of Ontario, I think \$7 would be a fair cost for that work. It is probable, I believe, but I cannot speak from experience, that the refining of the pig could be done by a modified open hearth or Bessemer process more cheaply than it could be done by the electric furnaces. It is impossible in a laboratory to duplicate the open hearth satisfactorily, and my refining was all done in an electric furnace; but I believe that eventually the material can be refined by the open hearth method more cheaply than by an electric furnace—or possibly by a combination of Bessemer converter and electric furnace.

We therefore arrive at an alloy steel made directly from the Sudbury ore, and containing the relative proportions of nickel and copper that occur in nature. For the steel which I made I tried to get average ore, so that the steel would contain about 94 to 95 per cent. of iron, two to four per cent. of nickel, and from one-half to one and a half per cent. of copper. The carbon was reduced generally to below one-half of one per cent., although it could be carried further if it is desired to do so; silicon was almost eliminated, and sulphur was below five-one hundredths of one per cent. This meets the specifications of the steelmakers except as to copper, and they would say you had fine steel there, if it were not for the copper.

Prejudice Against Copper in Steel

One of the steel companies, for instance, which is manufacturing for the English government at the present time, in large quantities, has said that it would like to make that steel, but they could not sell it. The British government specifies not more than .05 per cent. of copper in steel for ordnance and similar purposes, and you would have to undertake a missionary campaign to educate the users of alloy steel to the fact that copper is not detrimental. There isn't one of them that will buy copper-nickel-steel to-day offhand if they know that it is copper-nickel steel, and yet the copper-nickel-steel which people are making in Philadelphia and Washington—and they have made some in Pittsburg—is standing up to the same test that the nickel steel is called upon to stand. I had some bars made and tested them for tensile strength, elasticity, etc., and I found they stood up just as well as the nickel steel. We have been having some more made at the McGill University, but I have not heard from them yet.

Here is a pamphlet which you have probably seen—"The Influence of Copper upon the Physical Properties of Steel."[1] After a very extensive inquiry the authors cannot find that copper is detrimental to steel for any ordinary purpose. Mr. Clamer published a pamphlet on nickel-copper-steel a copy of which I sent you with my letter, and the tests, and those made by Mr. Matthews and Mr. Carpenter, both well-known metallurgists, tend to show that there is a prejudice against copper in steel which is not well founded. At the present time, that prejudice is the biggest stumbling block in the path of getting this process adopted by the commercial manufacturers of steel.

[1] Bulletin Am. Inst. Mining Engineers, No 82, for October, 1913

[*G. M. Colvocoresses.*]

As far as the cost goes, I have very carefully figured over in a number of different ways, the actual operating cost as I believe it would work out in manufacturing this nickel-copper-steel from the Sudbury ores direct; and I cannot find any reason to think, even on the most liberal estimate, that the steel would cost more than $30 a ton. That compares, as you know, very favourably with the cost of manufacturing nickel-steel to-day, where the nickel is purchased from one concern and alloyed with steel made by another concern. I think that on a large scale this nickel-copper alloy steel could be manufactured for $25 a ton; and my own whole proposition simmers down to one statement, when I say that I believe that the manufacture of nickel-copper steel directly from the sulphide ores results in a steel which is quite as good—not a bit better, but as good—as the ordinary nickel-steel of commerce, and at a considerably lower cost. There is no positive way of proving that statement until one actually does it, but any man going over the figures, I believe, will be satisfied that this material can be made much more cheaply than nickel steel by present methods, and anyone examining the tests of the physical properties of copper-nickel steel will be satisfied that it is as good as the nickel steel. It remains to educate the users to take it in place of nickel steel.

Prof. Burgess, of Wisconsin, wrote this letter on April 19th, 1911: I quote in part: "Our work has made us believe that the use of a copper-nickel addition to iron, if "properly taken up, would develop into a valuable matter in the field of alloyed steels. "There is a long standing and well-developed prejudice against the existence of copper in "iron and steel, but we believe that it is a prejudice which is not entirely well founded."

Of course, that is more or less non-committal.

Saving the Iron and Sulphur

Now, then, from the commercial standpoint, what I claim is that I can make an equally good alloy steel for less money than nickel steel. And from the conservation standpoint it appears to me that this process of mine has a great many good points: In the first place, there is no appreciable loss of iron—not more than is lost in the ordinary slag from an iron furnace. You have the 40 to 45 per cent. of iron which is taken out of the ground, and it all comes back in your finished product.

In the second place, your sulphur will have to be roasted out in a furnace constructed for roasting sulphur, and all of that sulphur can be utilized sooner or later. I am not prepared to say that the sulphur can be profitably utilized at the present time in the district around Sudbury. I believe it could, but I think it would be a very close question. At all events if utilized even with no profit it would not be a detriment to the agricultural interests of that district; and a company operating in this way would not need to fear law-suits and damage claims on account of the sulphur fumes. In the third place, I am almost positive that if this process were adopted it would have to be carried on very near the ore bodies; it would be quite out of the question to transport this ore, at least until you get it in the form of pig, anywhere out of the country. You are favoured in Canada, especially in Ontario, with cheaper water power than probably any other place on the continent of America. You are not favoured with cheap coal or other forms of fuel, but using, as I believe would be used, a large percentage of electric power and a comparatively small percentage of fuel, I know that this alloy could actually be made more cheaply in Ontario than it could in any neighboring part of the United States. Of course, if part of it were used, as undoubtedly it would be used in the United States, it would be a simple matter to export the pig iron over there, which would probably go in free of duty under our new tariff, and that could be refined in the United States to avoid the present duty on refined products.

DR. MILLER: Speaking about using the sulphur; suppose the ore were brought down to the Niagara district, wouldn't that sulphur go a long way towards paying the freight on it? A. What commercial use would you propose?

Q. Well, for making sulphuric acid, for instance. A. I think it would, in that district. I think if it were taken to any point on the Lakes that, in all probability, there would be a market for sulphuric acid.

Q. There is a fairly good market, normally, here, and an especially good one now. Iron pyrites with 45 and 50 per cent. sulphur generally brings, say, about $6 per ton? This ore of yours on the average, would amount, roughly, to what, in sulphur? A. About 25 per cent. roughly.

Q. And if you saved nearly all that sulphur that would be worth, roughly, $3 a ton. A. I should think so.

Q. Well, that would go quite a way towards paying the freight down here, wouldn't it? A. The freight on nickel matte Sudbury to Bayonne is $6 a ton, I think; that takes the rail freight all the way down.

Q. But if you were bringing it down to the Niagara district where the sulphur would be available, you would have it right there where you could use it. You couldn't ship it very well from Sudbury as sulphuric acid, at present? A. I had in mind if I had been able to raise the money for this (which I was not) I would have carried out this process at Welland or

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vicinity, which seemed to me the best place for it. I went up there and looked over a number of sites, but I don't pretend to know enough about the sulphuric acid market to make my opinion of any value on that point at all. I think, in fact I am quite sure, that a market for that could be worked up, and the sulphur would, at least, a few years from now, be a valuable asset.

MR. SUTHERLAND: A good deal of the Sudbury ore carries 2 per cent. copper. When you make your concentration by fire, you double the amount of nickel and copper in your pig as compared with the original ore, that would make 4 per cent. of copper in the pig; or eighty pounds at 20 cents a pound, say $16, which you would lose? A. Most of the ore I experimented on was lower in copper than that, considerably lower; but in the case you mention when the pig was in the refining furnace I simply alloyed with pig iron or scrap iron. I have had pig from the Sudbury ore that carried 4 per cent. copper and probably 8 to 10 per cent. nickel, or thereabouts. In fact, nearly all the ores that I had carried a great deal more nickel than copper, and the pig ran about seven or eight per cent. nickel to 2 or 3 per cent. copper. Now, I simply added to that in the refining furnace an equal volume of scrap iron, without any nickel or copper in it at all, and I produced a steel with 4 per cent. nickel and 2 or 1½ per cent. copper. If I chose to add another equal volume of iron to that, I could get it down to two and one, making a 3 per cent. alloy, and it is obvious if you were doing this in a district such as Welland, right near the Buffalo plants, the Lackawanna Steel Company, etc., you could procure your scrap iron and pig iron very cheaply for alloying your alloy pig which would be produced from the Sudbury ores.

Nickel-Copper Steel from Blast Furnace Slag

I also experimented at the same time with making alloy steel from the slags of the ore. That is something a good many have experimented on before, and they always stumbled over the same block—the copper. It was a well known fact that you could make steel from those slags. Major Leckie tried it, assisted by Mr. H. A. Morin, and I think others, too. They made steel, but they thought it had too much copper in it, and also sulphur. I took care of the sulphur by an electric refining furnace, and I got steel which had a very low percentage of nickel and copper, approximately one per cent. of nickel and a half per cent. of copper, or possibly a little less than that. I got some old slags that were a little higher in nickel and copper, and I got a little higher figure in the steel. The principle is exactly the same as treating the ore, the only difference being that you do not have to roast it, as you have very little sulphur to start with, and that sulphur can be taken care of by an electric furnace; and you arrive at exactly the same result with the percentages of nickel and copper consistently reduced. Now, my idea was that if this thing got started in a commercial way it would pay to operate by the present method in part, and by this new method in part.

For making refined nickel or Monel metal, of course your plant for making nickel-copper steel is no good; you have got to make the nickel-copper matte, and then separate the nickel and copper either by the Mond or Orford or some other process. A large amount of the nickel is used pure, as in some coinage for instance, and for alloys as in nickel silver, and so forth; but there is no reason why the slag from the blast furnaces making this nickel copper matte should not be run directly into either a blast furnace or an electric furnace (an electric shaft furnace), and instead of being run out to waste it could be utilized as a base of the iron pig and of the alloy steel, fluxing the slag with limestone in exactly the same way that you flux iron ore. You would have a very great advantage if you treated the slag before it cooled, as you would save all your heat units, and that would undoubtedly be the economical method of working it. Of course I never was able to experiment on the slag before it cooled, but the work I did was on the cooled granulated slag. As a matter of principle, it would be a great deal better to use the hot slag. By running your blast furnace in what would be considered now as a very poor manner, you could make a foul slag by preventing all of your sulphur from combining with the matte. You could then allow a little sulphur to combine in the slag, and you could get a slag, which, instead of containing (as the average Sudbury slag does to-day) about half of one per cent. combined nickel and copper, would contain up to one per cent. or more combined nickel and copper. That would bring your percentage of metals in slag just about right, or nearly right for manufacturing the alloyed nickel copper steel. You would not get all the metals in your matte, but you would get them in your steel, and you would not lose the values in the slag at all as you do now; you lose one-half of one per cent. nickel and copper that is slagged off in these furnaces.

I have gone into the thing very carefully, and I cannot see any reason why that cannot be done, and done at a commercial profit. The one thing that it requires is a large plant; it requires the expenditure of a lot of money. The operators in the district at the present time are making much money, and perhaps they are not over anxious to go in for anything new in that line, which would mean only a comparatively small additional profit. At the same time, I am perfectly satisfied it would mean a profit, and with a big plant for the

manufacture of the nickel-copper matte, and pure nickel and copper or Monel metal by the refining of the matte; also a plant for the manufacture of nickel-copper alloy steel directly from the ore, and for manufacturing nickel-copper alloy steel from the slag of your matting furnace, you have got a proposition that on paper looks very nice, because it really provides for utilizing every bit of valuable material in the ore from start to finish. Nothing valuable is lost; your sulphur isn't lost; your iron isn't lost, your nickel and copper losses are a good deal less than they are at the present time.

Large Scale Experimental Work Required

The whole question is whether this is a dream, or whether it is an actual, practical, commercial fact; and I can only tell you what I have done in small laboratory experiments, and what figures I have been able to work out from what I know of the practice in the Sudbury district and other places where similar work is being done. What I wanted was to have people who were sufficiently interested go ahead with some experiments on a small commercial scale. It never pays to start in on big experiments, because if you are not successful you lose a lot of money, and I know as well as anybody does that many processes which work out nicely in the laboratory don't work out well when you get down to operating on a large scale, and under local conditions near where the mines are working and where you have to treat the materials. There is absolutely no other way of proving this thing than to go ahead with a commercial experiment.

MR. SUTHERLAND: You think that the present nickel companies are making such a large margin of profit, and this is so small that it would not interest them? A. I don't think that eventually the profit would be small. I think it would be fairly large, but it calls for a very large investment in new plant. Their profits would be but little larger than they are at the present time.

Q. So there isn't any great advantage? A. No great advantage to the nickel companies —no. At the time I started working on this thing I was in the employ of the International Nickel Company. I was with them for twelve years, and I talked it over with them. I wanted them to let me go ahead and experiment for them; they had no objection to the idea, but did not see they had anything to gain by adopting it. So that practically all the work I have done has been done entirely at my own expense and on my own hook.

MR. GIBSON: Would it be possible to conduct operations on a commercial scale in some existing steel plant? A. I don't know of any plant at the present time that would be equipped for that, but it would be possible to do so by arranging for a comparatively small additional equipment. For instance, you have got to combine the Wedge roaster, or some form of roaster, with the blast furnace. Now, none of the steel plants have roasters at the present time. They don't need them in their business. The roasting could be done very cheaply. A small amount could be roasted in an ordinary hand-rabbled calcining furnace, such as was used twenty-five years ago in copper works—though, of course, if they were working on a commercial scale they would need a regular revolving multiple hearth roaster—then you could utilize a small blast furnace for smelting to pig; no trouble about that at all. You have got to have an electric furnace for refining, or else make such arrangements as you can to refine by open hearth; and that would require additional expense. I am not sure whether "the Sault" steel works have an electric furnace or whether they have torn down that old furnace they had last time I was up at their plant. The hardest part is to regulate the carbon. That is a matter that requires some experience. In Philadelphia they used the Hering furnace for refining. I realize that the experiments which I made were on a very small scale. I sent a quantity of ore, some hundreds of pounds, to McGill University two weeks ago, and I hoped that they would have had their experiments finished in time for this meeting. Of course, they won't settle actual costs of manufacturing on a commercial scale. If I could convince the steel users that the copper is not disadvantageous, if some of the large users of nickel steel to-day would go to the expense of experimenting with the nickel-copper steel, and would say that as a result of their experiments they were satisfied to accept the nickel steel with copper in it, I am convinced that the steelmakers would enter this business. In fact, I have had pretty good assurances that they would. I went down to Washington two years ago, and tried to get the Navy Department to carry on some experiments. They were very much interested, and told me if I would make armour plate of nickel-copper steel they would shoot any number of shells into it at their expense. It costs about $15,000 to make an armour plate. The only people in the country who can make it are the Bethlehem Steel and Carnegie and Midvale, and I don't think either of these firms is yet ready to take the matter up. I had the proposition up with the Bethlehem Steel Company, and they were interested; but they cannot get away from the copper. Mr. Buck, their vice-president, whom I saw on two occasions, and who is very familiar with the Sudbury conditions, said, "Well, it may be all right, but where are we going to sell this nickel-copper steel?" They are making, of course, an immense amount of ammunition for the British government at the present time, and those specifications against copper are particularly hard to overcome. The automobile people specify against

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copper, too, but a lot of copper in steel has been "pawned" off on them by steel manufacturers and they had a lot of tests of this copper-nickel steel made—their Monel metal steel—as against the nickel steel they were supposed to deliver.

MR. SUTHERLAND: But they never knew the difference? A. No, not once in a hundred times, unless they analyzed it; as long as they have been getting the ordinary good quality of steel they let it go right along; but if there is any kick coming they will analyze it. Various users had been supplied, I was told, over four thousand tons of copper-nickel steel up to about a year and a half ago; I don't know how much since. In Germany, if I was correctly informed, they have been using nickel-copper steel for some years for certain special purposes, and found it particularly valuable for those purposes. What these were using it for, I don't know, but I was advised that they were using it and specified it:—material that was delivered to the German government.

Sulphur the Culprit, not Copper

MR. GIBSON: Is the prejudice against copper in steel founded on actual experience, or is it, as you have explained, largely due to the presence of sulphur and not of copper? A. My personal belief is that the prejudice is entirely founded on the fact that all the copper steels made a few years ago contained sulphur in a quantity that was detrimental. The English steelmakers had a conference on the subject some ten or twelve years ago, and they all agreed that copper was harmful in the steel. The analysis of steels that they gave all showed in conjunction with the copper, a certain percentage of sulphur; and when Professors Burgess and Aston and others in the States began to investigate, they went back and raked over the fact that sulphur was always present where copper was. That appeared to be the "nigger in the wood-pile," the real trouble. I found one thing that was very interesting in connection with the nickel-copper steel, and that was this: if the copper exceeded 50 per cent. of the nickel in the steel, or possibly 40 per cent., the effect appeared to be detrimental to the steel. For instance, a steel containing three per cent. of nickel must not contain more than one and one-half per cent. of copper. If it does, it is brittle, but up to approximately 40 per cent. or 30 per cent. of the nickel, the copper replaces just exactly so much nickel in the steel.

MR. GIBSON: Take a steel that contains no nickel: would copper be detrimental? A. I believe it is, over a certain percentage.

Q. Wouldn't that be the case with those English steels? A. The English steels had no nickel at all. They were simply copper steel. Now, they are making copper steels to-day up to one per cent copper which seem to be absolutely all right. They are being used for roofing sheets and rails, and they are giving very good results. They have tried them on the New York and New Haven railroad. But above one per cent., it does seem as if copper is detrimental in its effect upon steel. On the other hand, if you have over 3 or 4 per cent. of nickel, a steel will stand one per cent. of copper without doing any harm.

MR. YOUNG: Will carry up to 50 per cent.? A. Yes, but preferably not more than 30 per cent. I took 4 per cent. nickel steel, and after testing it, that 4 per cent. nickel steel was almost identical with nickel-copper steel with 3 per cent. nickel and one per cent. copper. This bulletin contains a complete history of all the tests that have been made, but I really think that the case against copper in steel is a very poor one when the copper does not exceed a certain percentage.

MR. SUTHERLAND: Are the United States requirements as stringent as the British government's requirements just now? A. In the United States Ordnance Department, except for certain special purposes, they do not specify against copper in steel, as a general thing, but their steels have to stand up to the physical tests that are required.

Q. But the large munition manufacturers in the States now, or at least the steel people, are all working on British contracts, and have to abide by the British specifications? A. Very largely, at the present time. When they were building the Panama canal they specified against copper in steel, and there was some steel sent down there with copper in it. I think it was sent down by the Crucible Steel Company. It contained above one-half per cent. of copper, and it was thrown out. The Crucible Steel Company's man went down there and had that steel experimented with in competition with the steel that met the specifications; it fulfilled every single one of the physical requirements, and as a result of that, the engineers took the prohibition off copper on all their future specifications.

MR. GIBSON: The process you have described would be more particularly suitable for the ores of Sudbury? A. That is the only kind of ore it is suitable for.

Q. It wouldn't apply to the ores of New Caledonia? A. No. But you can make nickel steel from the New Caledonia ore without any copper in it. That has been done years ago by the French. The iron in the average New Caledonia ore is only 10 to 15 per cent., and you can alloy it with copper if you wanted to do so.

DR. MILLER: There is a good deal of ore in New Caledonia that is thrown away? A. Yes, a great deal is thrown out, at some of the mines—their shipping product is only about one-sixth of the actual nickel-bearing material they mine. That is where the cost comes in; otherwise it would be the cheapest nickel mining in the world.

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Cost Less Than Nickel Steel

Q. At what price do you suggest that this nickel-copper steel might be sold? A. I think I stated that it could be profitably sold at $40.

Q. And the steel itself, without nickel-copper, would sell roughly at what? A. Well, at the present time ordinary carbon steel is selling at about $30, that is, rolled into shapes.

Q. It might sell at $25 or $30: there would be a difference of $10 to $15? A. A difference of $10 or $15, yes. You could not possibly hope to manufacture steel from those sulphide ores which have to be roasted, as cheaply as you could manufacture steel from the Michigan ore for instance. That steel costs about ten or fifteen dollars less.

Q. No, but the point I was trying to get at was what you would really be getting for the metals, copper and nickel, in your steel? A. You would be getting less than you get to-day.

Q. Well, your steel contains roughly— A. Say, on the average, 2½ to 4 per cent. of nickel and not more than one per cent. copper. That would be $16.50 for the two, plus the steel. Assuming fifty pounds of nickel at 25 cents a pound, that would be $12.50, and $4 for the copper; the iron that goes into that to a steelmaker wouldn't have a value of more than $20.

Q. Of course, when normal times come again they may sell nickel at a good deal lower price? A. Well, assuming that nickel is sold at 25 cents a pound, and that a man to-day wants to alloy his open hearth steel and make three and a half per cent. nickel steel, he buys 70 pounds at 25 cents; he pays $17.50 for that, plus the cost of his steel, which we will say, would be about $20; that is $37.50. Now, I claim that for $30 that same ton of three and a half per cent. alloy steel can be manufactured direct. As a matter of fact, a great deal of the nickel is paid for at a higher price than that, and goes in the steel.

Q. Isn't there a likelihood that in the future it may be sold at a considerably lower price? A. That I don't know.

Q. It was sold at 25 cents in the old days, wasn't it, when the Vivians were working there? A. At the time the Orford Copper Company and the French company got into competition they sold it down at 22 cents or thereabouts, but that was only for a short while, and I don't think since then it has been sold at so low a figure.

Nickel-Copper Steel a Homogeneous Product

Q. Well, if the nickel people could make fifty per cent. on the cost, it would be a pretty fair profit, wouldn't it? A. I should think so. I don't claim that any company engaged in the manufacture of nickel to-day would benefit by this process. Their profit would be no greater than it is at the present time. They probably make as much profit out of selling the nickel that goes into the nickel steel as they could expect to make by selling the nickel-copper steel itself, figuring interest on the plant and everything else; but I do claim that this is the logical and proper way to make the nickel steel, or rather nickel-copper steel. When you have got your nickel combined, with 40 odd per cent. of iron by nature, you ought to utilize that iron, and make your nickel steel directly from the ore; not take away and slag off the iron, and separate the nickel and copper by an expensive process, and then put the refined nickel, or the nickel oxide back into iron that comes from some other source. I think I am right in saying, also, that the nickel-copper steel made in this way is in some respects superior steel to the nickel steel that is made by alloying in the open hearth furnace. The reason of that is that all three metals, iron, nickel and copper, are kept in combination right through from the start, and the composition of this alloyed steel is homogeneous. When you alloy in the open hearth the molten steel with the nickel oxide, you run a very big risk of segregation, and much nickel steel must be thrown out as defective. It would be foolish for me to say from the little experience that I have had that this would be the way of it in a big plant, but it seems reasonable and logical that my steel would be more homogeneous than any made by the present method.

MR. GIBSON: You don't concur in the opinion that the only proper way to make nickel steel is to add the nickel in the furnace? A. No, I don't believe in it. What is the basis of the argument? If you have the nickel and the iron together, and you keep them together right through, why should the result be inferior to nickel steel that is made up by two metals being put together at the very last? Take Monel metal; it is not made by separating nickel and copper, and then putting them together again; it is made by keeping the nickel and copper in combination right through from the start. And the Mayari steel is a steel that has many good qualities.

DR. MILLER: The point was made that the Mayari steel was not as good, because the constituents were there in the original ore. A. That steel has chrome in it, and chrome-nickel steel has different properties from straight nickel steel.

MR. YOUNG: Would nickel-copper steel compete with the ordinary steel on a commercial basis? A. Unquestionably, it would not compete with ordinary steel, mild steel, or carbon steel, because it would have special physical properties comparable to nickel steel. Now, take matters as they stand to-day, and assume that they purchase 70 pounds of nickel to add to a steel. They pay for that $17.50, 25 cents a pound. (Of course, they may pay more

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or may pay less, but assume that to be what they pay; though I don't think you can get it as cheaply as that under the circumstances.) They add that to, say, $20 worth of steel. Their actual cost for that ton of nickel steel is $37.50. My actual cost of the manufactured steel is estimated at $30.

MR. YOUNG: Can you give us the items of cost? A. Yes. I have figured everything here on a very liberal basis. For instance, I have allowed for each ton of ore, mined and roasted and sintered, $2.50 for mining. It is not costing anything like that at the present time. I have allowed for crushing and roasting 50 cents, and for sintering and transportation $1.00. That would be assuming it was going to some point several miles away, but not away down to the Niagara district. Roasted and sintered the ore costs $4.00 a ton; $8.00 per ton of pig; two tons ore to the ton of pig. Coke, that is, assuming you smelt in an electric furnace, costs you about $2.25. These figures are based on an English estimate of the manufacture of steel by the electric furnace, and on conditions in the Sudbury country. Lime, 30 cents per ton of pig iron. Electrodes $0.60. Power at $20 per horse-power per year, which is higher than you expect to pay in that district, costs $7.00, and labour $3.00 on the last basis of labour value. The total cost is $21.15 per ton of impure pig for refining, and allowing 2,008 pounds of pig for one ton of steel, comes to $21.25 per ton of steel. Add to that burnt-lime 30 cents, iron ore 20 cents, ferro alloys, manganese, etc., 50 cents, electrodes 68 cents, power $1.15, labour, etc., $3.80; that brings the total cost to $27.88 per ton of refined steel, and allows $2.12 for selling expenses and general expenses which would bring it to $30.00.

MR. GIBSON: Are you allowing for overhead expenses in the $2.12? A. $2.12 would cover the overhead expenses.

Costs by Blast and Electric Furnace Equal

Q. Which do you think is the cheaper, smelting by the blast furnace, or the electric furnace? A. It would all depend on what price you can get coke for. Coke is the determining factor, and electric power. If you can get electric power for $16 per horse-power per year, and coke at $7 per ton, which is the cost at the present time, I believe, in the Sudbury district, you have an advantage in using the electric furnace. If you could import your coal and make coke in by-product ovens, and get some credit for your sulphur as a fertilizer in conjunction with the ammonium sulphate (a natural product of coking) and your coke should cost you five or six dollars a ton, you probably would have a slight advantage in favour of the blast furnace.

Q. But the conditions as they are at the present time in the Sudbury district would favour electricity? A. I think slightly, but the advantage wouldn't be very large. At $12 a horse-power year, electric smelting would undoubtedly be cheaper, and it would be the preferable method, because the cost of refining electric pig is less than that of blast furnace pig. You make a cleaner pig and it requires less refining. It is very difficult to figure these things closely, on small laboratory experiments. I cannot tell you anything more than theoretically, and I have compared, for instance, electric steelmaking costs in California and Norway, and several other places, and taken local conditions as they are in Sudbury and used those figures; substituted local figures for the ones that are given in these other places, and based my estimates in that way.

DR. MILLER: How many tons of ore roughly, should be treated in a day to put this on a commercial basis? A. I think that a plant having a capacity of one hundred tons a day could be started, and the product would sell itself after that. I mean if the operations were successful as my belief is they would be. I think that the other companies would be anxious to treat their ore in this way.

MR. GIBSON: Would that be a normal capacity for an electric furnace on that ore? A. Well, it would be a very large capacity for any ordinary furnace. About fifty tons ore a day is, I think, as much as any electric shaft furnace takes, and two of these could be operated as a hundred-ton plant. That would mean the production of say, fifty tons of steel a day, say fifteen thousand tons a year. Fifteen thousand tons of nickel-copper steel a year would only supplant, of course, a very, very small percentage of the nickel steel that is sold to-day. Some of the large steel companies in the United States sell more than that in a month.

MR. SUTHERLAND: What would the freight on the nickel-copper steel pig be from Sudbury to where it would be used? The greatest market would be in the States, wouldn't it? A. You have also a big market in England. You are not making refined nickel; you are making nickel steel or a substitute for it. Any of the steelmakers that have rolls and the ordinary equipment for casting, can utilize nickel steel. It doesn't require a plant with the open hearth equipment for alloying the nickel with the steel, which is only found in a few of the larger plants. If you make the nickel-copper steel ingots you will find they will be marketable wherever nickel steel is used. For instance, if you are using nickel here in Canada for bridge work or for armour plate it could be used right here, and, of course, it could go to England for all uses there, and to the United States. The freight should not exceed to Pittsburg, we will say, about $6 a ton, about the same, roughly, as the freight on matte to Bayonne.

[*G. M. Colvocoresses.*]

DR. MILLER: What would be the approximate cost of a plant like that treating a hundred tons a day? A. A complete plant to treat approximately a hundred tons a day would probably cost $250,000. That includes the roasting equipment, the smelting equipment, the pig refining equipment and everything. My own idea was to have a small experimental plant put up at Welland that would have cost about $15,000, and would have treated about five tons of ore a day. If that plant were successful in its operation, I felt confident that some of the steel companies or others would be sufficiently interested in the matter to go ahead with a larger plant, such as would be necessary to get this thing on a commercial basis. I think an expenditure of $15,000 for a small experimental plant would tell the story, and that such a plant after it had operated for a period of three months or thereabouts, would pay its own way very nicely.

Q. Suppose there was a company organized on a large scale to take up that process, they might have difficulties now in getting large holdings outside of the companies that are operating in the Sudbury area? A. I hoped, if this process were successfully applied, possibly one or other of the operating companies there, might be combined with a business of this kind.

MR. SUTHERLAND: The company using that process wouldn't make any refined nickel? A. Not unless they chose to separate it and make it by some of the established processes. I didn't contemplate in this process the manufacture of any refined nickel at all, but two-thirds of all refined nickel is used in alloy steel to-day.

Converting Sulphur into Sulphuric Acid

MR. GIBSON: You spoke of getting rid of the sulphur fumes. How would that be accomplished? A. At the present time the sulphur is roasted in open heaps, and it spreads over the country and is a considerable detriment. Now, if you roast the ores in a furnace, a multiple hearth furnace such as the MacDougall, Herreshoff, or Wedge, the fumes pass in a flue, and through that flue can be conducted into the chambers where sulphur (by one method or another) is precipitated and utilized for the manufacture of sulphuric acid, or possibly, for metallic sulphur. That is being done for the Tennessee Copper Company where they were obliged to stop letting sulphur go to waste on account of the damage to the crops.

Q. You think the sulphurous fumes would be rich enough to afford the raw material for making sulphuric acid? A. No question you would not get as much sulphur out of Sudbury ore as you would from iron pyrites, but most of the sulphur you have could be utilized.

MR SUTHERLAND: Well, the fumes you use have only six or seven per cent sulphur? A. In the fumes, you mean, or in the ore?

Q. No, in the fumes? A. I don't think it exceeds that amount.

MR. GIBSON: The fumes, for instance, that come from the sintering furnace at the Mond nickel plant, are they considered suitable for the manufacture of sulphuric acid? A. I think they would be. The fumes that come off the roast heaps, I know, are suitable for it, and Mr. Sjostedt in 1904 roasted pyrrhotite in kilns for commercial purposes.

Q. But you cannot trap them at the roast heaps? A. No, from the roast yards they spread out all over the country. Exactly similar fumes are made from pyrrhotite by the Tennessee Copper Company, and at Philadelphia they are using the Rio Tinto ore from Spain with fifty per cent. sulphur, forty-five per cent. iron and one or two per cent. copper, and they utilize every bit of sulphur from that ore for manufacturing sulphuric acid. They recover the copper by leaching, and they take the iron and nodulize and ship it to the Bethlehem Steel Company who utilize all the iron and pay for it. There is a proposition that is worked in somewhat the same way that I propose to work this nickel.

Q. There is a greater proportion of sulphur than there is in the Sudbury ore? A. There is a greater proportion of sulphur, and the sulphur is one of their chief sources of profit. The Rio Tinto people make a profit on all the constituents of the ores, and at Ducktown (Tennessee) the sulphur made them more profit than the copper did, before this year, but the present price of copper has probably changed that situation.

MR. SUTHERLAND: Wouldn't conditions of temperature govern the manufacture of sulphuric acid? A. I don't think so. They made sulphuric acid at Anaconda, where the climate is very similar to the Sudbury climate, and my understanding was that it was no more expensive than in the southern section of the States, but they had no market for it, and therefore they never went into it on any large scale. They claimed they couldn't dispose of it out there; there was no market for sulphuric acid, and it won't stand transportation for long distances. Sulphuric acid has also been made at Sault Ste. Marie.

Electrolytic Refining of Copper

DR. MILLER: They don't seem to have any trouble with electrolytic refining out there at Butte, Montana? A. No; they refine copper electrolytically at Great Falls, and some zinc is being refined by the Anaconda Copper Company.

Q. Some refiners allege that our north country is unsuited to refining on account of the low temperature? A. Well, Calumet and Hecla moved their electrolytic refining up to Calumet,

[G. M. Colvocoresses.]

in Michigan, and the American Smelting and Refining Company have an electrolytic refining plant at Tacoma, Wash., and they are now enlarging that plant.

Q. That shows there is more copper being refined in the West now? A. Yes, a great deal.

MR. SUTHERLAND: Is it still true that 95 per cent. of the copper in America is being refined less than fifty miles of New York? A. No, nothing like that percentage. I could give you the exact figures, but I would have to look them up. But in round figures it is not more than seventy-five to eighty per cent. The American Smelting and Refining Company refine in part at Tacoma, and the Cuban copper and some South American copper is refined at Baltimore. The biggest refineries are still near New York, but the reason for that is on account of the market conditions, because the greatest copper market is around New York.

MR. GIBSON: No special physical conditions? A. Not that I know of. One of the Anaconda engineers told me that they had been refining near New York. He said they figured the whole thing out, and they found the labour in the West (in Montana) was about twice as expensive as in New York On the other hand, electric power was a great deal cheaper; the one just about offset the other, and they wanted to refine near their mines, so they built this new refinery in Great Falls, which is not yet in full operation.

DR. MILLER: Seeing Great Britain is a large market for nickel steel wouldn't it be well to have some of your material tested over there? A. Yes. The German government, for instance, experimented with all sorts of new alloy steels for years. They worked on the Krupp process for hardening armour plates which was superior to the Harvey process used in England, and they have worked out a lot of these special steels that they used in flying machines. They had regular provision for doing that. Now, there is nothing of that kind in the United States. The Naval Consulting Board at the present time are trying to get a five million dollar appropriation for a laboratory for experimenting with military materials; just the work that Germany has done. I don't think you have anything of this kind in Canada at the present time. I presume the British government have some provision for testing out materials, and perhaps the British government would be interested in testing some of this steel, and I should think they would be interested. It would be made entirely from their own ores and could be made entirely right here in Canada.

Q. Now, in case of material like the Alexo ore, containing about 6 per cent. nickel and half of one per cent. copper, you would have to add considerable iron? A. Yes, in any percentage you deem desirable. The copper is of no importance as long as it does not get too high. It merely replaces so much nickel, therefore you can carry your low copper in your nickel very readily, or a little more. By that, I mean there would be no need of considering the copper. You simply add enough iron to your nickel up to the desired per cent.

Q. Below one per cent. of copper would be all right? A. Perfectly all right.

Whistle a Typical Ore for Nickel-Copper Steel

Q. You would have to add iron to the Sudbury ore? A. If you had a high grade ore, yes. I don't think you would, for instance, if you take such ore as they had at say, the Whistle property. That was comparatively high in iron; it contained on the average not much more than two and a half or three per cent. in nickel, and was quite low in copper—I think about one-half per cent.; and if you just about double the constituents in that ore you get in the neighbourhood of five per cent. to five and a half per cent. nickel-copper steel, and five per cent. nickel steel is very largely used in some factories to-day. Three and a half per cent. is the standard for armour plate, but five is being used for a lot of ordnance purposes; also for the automobile manufacture five per cent. nickel steel is quite desirable.

MR. GIBSON: It is considered to have greater tensile strength? A. It has a little greater tensile strength, and it has more elasticity than lower nickel steel.

Q. Are your processes covered by patent? A. Yes, I have copies of the patents for the Canadian processes here. The Canadian government does not make printed copies, as the United States government does. These were made in my office. (Copies given to the Commission.)

MR. YOUNG: It would be a great advance if you could satisfy the British government that copper was not an element of weakness. A. Why wouldn't it be a great advantage for the British government to experiment? We have something here which I claim takes the place of nickel steel, at twenty or twenty-five per cent. below the cost of what they can buy nickel steel to-day. The great advantage would be for them to try out a little bit. I will make test bars and put them up against the nickel steel that is being used to-day, and I am willing to stand by those tests. The eight-inch shells that the Washington government are using to-day from that Monel metal steel will pierce armour-plate just as well as an eight-inch shell of nickel steel. I will send you a full copy of the McGill tests and their work. I have not arranged for the Chicago tests yet, but if I do I will send you copies of the results. I may have further tests made at McGill also. I think if a man went to Sudbury to-day, a man who was a good metallurgical engineer, but knew nothing whatever of the treatment of that ore

[*G. M. Colvocoresses.*]

as it has been developed in the past and is practised to-day, that he would say right away, "Why, here's an alloy iron ore and I am going to try it out," and if he found the resultant alloy steel as good as the alloy steel that is being made at the present time he would have one question in his mind: is this process cheaper than the present process? Now, when you come to figure the cost of roasting and matting that Sudbury ore, and the cost of bessemerizing it and shipping bessemer matte to the works in England or the United States and making the refined nickel by separating the copper by an expensive process, such as the Mond or the Orford process—when you come to figure that, and then put that nickel back in the iron got from some other source, as against my method of carrying all these metals right through your furnaces together and bringing them out as a finished product at the end, on paper there isn't much comparison; but one method is established and the other isn't.

MR. SUTHERLAND: You claim that up to fifty per cent. nickel the copper is neutral? A. If it doesen't exceed fifty per cent. of the content of nickel, or better thirty per cent., the copper appears to just exactly replace the same amount of nickel. Take nickel steel with three and a half per cent. of nickel, and nickel-copper steel with two and a half per cent. of nickel and one per cent. copper. Now, that doesn't have the properties of two and a half per cent. nickel steel; it has the properties of three and a half per cent. nickel steel. You add the nickel and copper together, and I will say that provided copper doesn't exceed thirty-five per cent. of nickel (I had some with forty per cent. that didn't seem to be quite as good as it might be), you simply add the copper and nickel together, and you have as good a steel as nickel-steel containing the aggregate percentage of nickel. Mr. Clamer investigated that, and he found that the structure of the copper-nickel steel was practically the same as the structure of the nickel steel; it became a homogeneous mixture. But if you let the coppcr get too high, then it begins to segregate and the steel loses some of the advantages of having a homogeneous structure.

[G. M. Colvocoresses.]

SECTION E

CHEMICALS FOR REFINING NICKEL

Evidence of Mr. A. Nieghorn, Agent Nichols Chemical Company, Toronto

(Toronto, 26th November, 1915.)

CHAIRMAN: We are anxious to learn everything possible as to the cost of such chemicals as are used in nickel refining or in connection with metallurgical industries, or the use of such waste products as may be obtained from the refining of nickel, in order to co-ordinate the two and see what the prospects are for that business here, but particularly the cost of chemicals and other things which would be used in connection with nickel refining. We have received certain information from England, Canada and the States; but we wanted to collect as much data as we could on such matters, for instance, as sulphuric acid, hydrochloric acid, carbonate of soda, salt cake and nitre cake, electrolytic soda and bleach. These are things which are directly used or required in connection with nickel refining. A. In giving figures you would of course have regard to those obtaining before the war.

Q. Yes. Suppose we take up sulphuric acid, say 66 degrees Baumé. A. That grade is the accepted standard for commercial uses the world over, the higher grades being used in special industries such as the manufacture of explosives.

Q. Yes. I do not think the higher grades will interest us so much. We have also to consider the question of the utilization of the sulphurous acid which is produced in the roasting and smelting, and it would be interesting for us to hear your views. A. That would depend upon the cost of making such by-product acid, the quantity and the price it could be sold at on a consuming market.

Q. Supposing the nickel smelters decided to use their gases for making sulphuric acid. What in your opinion would the prospects be, bearing in mind of course the consumption? It would be an advantage to them to utilize it to prevent complaints. A. That is rather a hard question. If they were to make their own sulphuric acid, I would say they would almost have to use it themselves.

Q. Or anyway, it would have to be used in the district? A. Yes.

Q. What prospects have Canadian sulphuric acid producers? Have they as good prospects as the other chemical industries have, and compared with the United States, assuming proper facilities for transportation and getting materials there? A. The producers of sulphuric acid in Canada have as good prospects as other chemical industries in Canada, but conditions differ somewhat from those existing in the United States, where the tonnage per capita is much greater. Take, for instance, the manufacture of fertilizer-acid phosphate. It does not pay to acidify phosphate in Canada where it has to be mined, while in the United States they have immense deposits than can be dredged. The principal markets for sulphuric acid in Canada are in Ontario and Quebec, the largest being in Quebec; and there the heavy business will be found to run to oleum for the manufacture of explosives, consequently displacing 66 degree acid. The amount of sulphuric acid used east of Quebec and west of Ontario is but a small percentage of the trade in this article in Canada. The sulphuric acid plants in Canada are, one contact unit plant in British Columbia and one chamber plant at Sydney C.B., while Ontario has a chamber plant at Sault Ste. Marie, one at Hamilton and two contact units at Sulphide, while Quebec has two contact units at Capleton. The overhead cost in manufacture in Canada must naturally be higher than in the United States, where there are several plants manufacturing individually more acid under one superintendent and staff than the six which are required for less production in Canada. It is of course impossible to consolidate all the Canadian plants at one point, because of freight rates which would be much higher than the extra overhead cost of manufacture.

Q. Is there much opportunity of exporting sulphuric acid from this country? A. Not under normal trade conditions.

Q Do you do anything to speak of with hydrochloric acid? A. The trade is not large, being confined principally to the galvanizing, tanning, glycerine and glucose trades.

Q. Do you make any bleach from hydrochloric? A. No.

Q. Your work is all electrolytic? A. Yes. Unlike Great Britain, both Canada and the United States make all their bleaching powder electrolytically.

Q. Where is hydrochloric acid made? A. Victoria, B.C., Hamilton, Ont., and Sulphide, Ont.

Q. And salt cake at the same points? A. Yes.

Q. At what points do they manufacture nitric acid? A. Victoria, B.C., Nobel, Ont., Hamilton, Ont., Sulphide, Ont., Rigaud, Que., Belœil, Que., and Capleton, Que.

Q. And the same would have nitre cake to dispose of? A. Yes, with the exception of Sulphide, where it is used in another line of manufacture.

Q. Is alkali dearer in Canada than in the United States or Great Britain? A. No. Soda ash has sold as low as 57½ in Toronto this year, which is below any figure which I have ever heard of in any country, and probably because the United States and British manufacturers compete for this market, none being manufactured in Canada at present.

Q. Is that the 58 per cent. alkali you refer to? A. Yes, 58 per cent. real sodium oxide.

Q. Is caustic soda relatively cheap in Canada? What would be a fair price on large orders? A. $1.90 per 100 pounds, Toronto, basis 76 degrees New York and Liverpool test.

Q. Where is that made in Canada? A. By the Canadian Salt Company, of Windsor, a very strong company, of which Mr. E. G. Henderson is president. I understand they contemplate extending their plant, and will shortly be able to take care of all probable requirements of Canada in caustic soda and bleaching powder.

Q. What would be a fair price for sulphuric acid 66 degrees? A. In bulk tank cars, 60 cents per 100 pounds.

Q. You were telling me the other day of the use of nickel sulphate for hydrogenizing oils. A. Yes. Nickel sulphate is used as the catylizing agent.

Q. And the amount of nickel sulphate used in hydrogenizing of fats is greater than that used for electro-plating? A. Yes. Many times larger.

Q. Is this nickel sulphate made in Canada? A. Yes, in Ontario, from nickel-cobalt ores.

Q. What are the prospects of the development of paper and pulp manufacture and its effect on the chemical industry? A. Canada now supplies all the bleaching powder used in the manufacture of what is known as bleached pulp. Alumina sulphate has not yet been made in Canada. Bauxite, the raw material used in the manufacture of alumina sulphate has so far to be imported from Arkansas, and the net results have not been sufficiently attractive to the Canadian producer of sulphuric acid to induce him to attempt the manufacture of alumina sulphate.

SECTION F

ONTARIO WATER POWER AND THE MINING INDUSTRY

[NOTE.—Mr. H. G. Acres, hydraulic engineer, Hydro-Electric Power Commission of Ontario, has kindly prepared the following memorandum for the Commission on the water power resources of Ontario, and their availability for the uses of the mining industry. It gives a succinct account of the part which water power is taking in the development and working of the various mining districts of the Province, and of its possibilities in connection with the refining and treatment of metals and mineral substances.]

Classification of Water Powers

To get a proper conception of the economic relationship of Ontario's water powers to the mining industry, it is advisable to divide them into two general classes, based on method of use. On such a basis, certain water powers would be classed as suitable for purposes of ore production and concentration. In the other class would be included water powers suitable for purposes of reduction and refining. The word "suitable" is here meant to include all economic factors, such as capacity, geographical location, topographic conditions, etc.

Water powers of the first class above mentioned should, generally speaking, have capacities ranging from 2,500 horse power to 10,000 horse power and should be located not more than 50 miles from the point of use.

Water powers of the second class mentioned should have a capacity of not less than 10,000 horse power and should be located not more than 100 miles from the point of use.

Recent advances in the electric refining and reduction of metals appear to indicate that in the near future blocks of not less than 100,000 horse power will be commonly used to carry on this branch of the mining industry. This condition will naturally lead to the establishment of this branch of the industry at points adjacent to the larger sources of hydraulic power. In other words, while the application of hydraulic power to ore production and concentration is limited largely by the capacity of local sources of energy, the power resources available for reduction and refining purposes are limited only by the capacity of Ontario's larger inland water powers and the enormous potentiality of her boundary streams.

It is of course evident that no definite line can be drawn between these two assumed classifications, as a water power of, say, 25,000 horse power capacity might, under certain circumstances, be very profitably used for all of the various purposes above specified.

Water Powers of Northern Ontario

At this point it might also be well to refer to the often repeated statement that if the water powers of Northern Ontario were more extensively developed, a great impetus would be given to the mining industry through the cheaper working of prospects. The first point to be noted in this connection is that the inherent uncertainty of prospect development is so great as to put the consideration of this class of business beyond the pale of private or public enterprise. Furthermore, the individual amounts of power usually required are so small that the cost of service in most cases would not be within reasonable limits. It seems quite useless to hope, therefore, that hydro-electric power can ever be used, to any extent, to prospect the virgin mineral areas of the Province. This statement can, of course, be qualified somewhat in considering mineral areas immediately adjacent to established camps. Where a camp is using several thousand horse power of transmitted power in connection with actual mining operations, it is quite possible to prospect the territory for a few miles on either side of the transmission line by tapping off blocks of 100 to 300 horse power as may be required.

Cobalt Silver Area

In the Cobalt district the use of hydro-electric power by the mining industry is at the present time substantially limited to ore production and concentration. There are possibly other reasons why reduction and refining are not carried on in this district, but one reason is plainly in evidence, and that is that there are no local sources of energy of sufficient capacity to warrant the establishment of such an industry. On the Montreal river, within economic transmission distance, the Cobalt district has in the neighbourhood of 9,000 horse power of developed and undeveloped capacity still available, and this is probably not more than sufficient to meet future demands for ore production and concentration. For large blocks of power, such as would be required for reduction and refining purposes, the Cobalt district must have recourse to the water powers of the upper Ottawa in the Province of Quebec.

Porcupine Gold Area

The Porcupine district uses hydro-electric power for production purposes to the limit of present development, which falls considerably short of meeting the existing demand for this class of service. The installed capacity of the existing plants is, however, capable of considerable increase, and it is understood that plans for enlargement are now under consideration. These existing developments are located on the Mettagami river, upon which are also located three as yet undeveloped sites within reasonable transmission distance, having an aggregate capacity of approximately 9,000 horse power. It would seem, therefore, that as regards power for concentration and the production of ore, the Mettagami river is capable of meeting the requirements of the Porcupine district for some time to come. For the supply of large blocks of power, such as might be required for reduction and refining purposes, the best and possibly the only source of supply for the Porcupine district is the Abitibi river. Upon this river approximately 20,000 horse power could be developed under favourable topographic conditions at Couchiching Falls, and 30,000 horse power developed under rather unfavourable conditions at the Long Sault. It may be considered therefore, that the Porcupine district can obtain sufficient power from local sources within the Province to meet the demand arising out of an extensive development of all branches of the mining industry. The district is fortunate in that the transmission distances involved are not, as a rule, great, and the main factor governing the price at which power could be supplied from the sources mentioned is the extent of the market now available, or assured for the future.

Sudbury Nickel-Copper Area

In the Sudbury district the quantity of hydro-electric power now absorbed by the mining industry is greater than any other district in the Province, the amount of power now developed or in course of development for this purpose being approximately 19,000 horse power. At the present time this power is being supplied from the Spanish river and its tributaries, and from the Wanapitei river. These rivers may be considered as the two sources of local supply available to the Sudbury district in connection with the production and concentration of ore. The larger water powers are located on the main stream of the Spanish river, and are now developed to full capacity. The undeveloped capacity on these rivers, including the tributaries of the Spanish, may be taken to be approximately 15,000 horse power, the capacity of the largest individual site being in the neighborhood of 5,000 horse power. These water powers may therefore be classed as suitable only for purposes of ore production and concentration.

For what may be considered a local source of power for reduction and refining purposes, the Sudbury district is limited to the water powers on the French river. The canalization of this river in connection with the Georgian Bay Canal project will make available three power sites, each of which may be considered as having a capacity of about 10,000 horse power or 30,000 horse power in the aggregate. The topographic conditions are such that only one of these possible sites, the Chaudiere, can be cheaply developed without the assistance of the canal works. Unfortunately, this site happens to be the one most remote from the market district, and the advantage which would be derived from favorable topographic conditions would be largely offset by the high transmission cost.

The Sudbury mining district therefore cannot be said to be ideally situated as regards the supply of power for reduction and refining purposes under market conditions now existing, but at the same time, if a really energetic and permanent development of this branch of the industry should occur, power would be obtained from the French river, possibly even previous to any canal construction, at prices which would compare fairly with those now prevailing in other parts of the Province. Furthermore, it is not improbable that the development of the reduction and refining industry may ultimately be sufficiently extensive to bring the Upper Ottawa within economic range as a source of power for the Sudbury district.

Throughout the remainder of the Province there is no concentrated development of the mining industry at all comparable with that in the districts so far mentioned.

The Michipicoten Region

In the Michipicoten district, hydro-electric power developed in connection with the mining industry is used solely for the production and concentration of ore, all power so used being at present developed on the Michipicoten and Magpie rivers. There are no water powers of large capacity in this district, but there is a considerable surplus of undeveloped power available in blocks up to 5,000 horse power, which might be utilized for the further development of ore production and concentration. If the Montreal river[1] is taken into consideration, the amount of power available for this purpose might be considered not less than 15,000 horse power. Most of the individual sites are capable of easy development, but in several instances transmission costs would be a discounting factor, not so much by reason of the distances involved, as on account of the extremely rough and unfavorable nature of the country over which the lines would pass.

[1] This is not the Montreal river mentioned in connection with the Cobalt district

[*H. G. Acres.*]

North Shore of Lake Superior

Along the north shore of Lake Superior the development of the industry is fraught more with possibilities than with realities at the present time. In this connection the development of the great iron ranges in the Nipigon basin will come into prominence when a process for the electric reduction of ore has been perfected, and with 100,000 horse power capable in the main of cheap development, on the Nipigon river, it is reasonable to predict the growth of an important iron industry in this territory.

On the Kaministiquia river at least 25,000 horse power remains undeveloped, and can be cheaply delivered to Port Arthur and Fort William whenever the market prospects are such as to justify development. While some portion of this available power could be used for the reduction and refining of metals, it is probable that the bulk of it could more advantageously be used for manufacturing purposes and for industries connected with the transfer of freight at the head of the lakes.

Rainy River District

In Rainy River district, the power resources are far in excess of any present demand for mining purposes, and it seems likely that this condition of affairs will continue. None of the gold prospects or working mines on the Seine river, for instance, have developed sufficiently to justify the supply of hydro-electric power. In Lake of the Woods district the known mineral deposits are not adjacent to any water powers capable of economic development; in White Dog falls on the Winnipeg river, the Province possesses a water power of the first magnitude, but its remote position rather discounts the possibility of its being used for the refining or reduction of ore.

Eastern Ontario

In Eastern Ontario, substantially the same condition exists as in Rainy River district as regards the relationship between the available supply of hydro-electric power and the available market. It would seem that the Trent river has ample power capacity developed or undeveloped to meet any of the various requirements of the mining industry in its basin. There is a considerable surplus of developed power now available along the Trent canal, and there is approximately 30,000 h.p. undeveloped in individual blocks ranging from 2,000 to 10,000 h.p. The existence of water communication with the Great Lakes through the Trent canal justifies the prediction that some of the larger of these blocks of power may be used in the future for reduction and refining purposes. The existence of the Canal works simplifies to a large extent the development of the Trent water powers, and at some of the larger of the above-mentioned sites reasonably large blocks of power can be developed at a cost of not more than $15 per horse-power per annum.

The tributaries of the Ottawa river, including the Petawawa, Bonnechere, Mississippi and Madawaska, have a large aggregate of available power at present undeveloped, but with the exception of the High Falls site on the Madawaska, which has a capacity of possibly 20,000 h.p. with storage, none of these sites can be considered as adapted to the use of the mining industry except for purposes of ore production and concentration. As previously stated, the amount of power available in this district for such purposes is very greatly in excess of the present demand, more especially as the Ottawa river can be considered as a source of local supply.

Summary of Available Power

As related to the above discussion, the following tabulation is submitted, showing the approximate amounts of power locally available for the use and development of the mining industry in the various districts mentioned, exclusive of the quantities now in use:

District.	For Ore Production and Concentration.	For Reduction and Refining.
	Horse-Power.	Horse-Power.
Cobalt	9,000	Quebec sources
Porcupine	9,000	50,000
Sudbury	15,000	30,000
Michipicoten	15,000	......
Lake Superior	25,000	100,000
Rainy River	10,000	50,000
Trent	10,000	30,000
Ottawa	10,000	40,000

[*H. G. Acres.*]

In connection with the price at which power could be supplied to the districts above specified, it would be entirely misleading to discuss the matter in general terms, as the final price of power delivered to the customer is governed by conditions which have a wide range of variation, the more important and more variable factors being available market, topographical conditions, transmission distance and available capacity. For this reason costs can only be discussed in relation to a specific proposition after the variable factors in connection therewith are known and appreciated.

Outside of the Mettagami and the Abitibi rivers very little of a definite nature is known concerning the power resources of the rivers flowing into James bay. It is, however, certain that north of the Transcontinental railway there are a number of power sites of large capacity capable of fairly easy development, and if a mining industry should develop in the future in this territory, there is definite assurance of an adequate power supply for the requirements of any class of service.

The Great Boundary Rivers

Owing to the fact that it is economically possible to ship rich concentrates to considerable distances from the point of production for reduction and refining, other sources of power must be considered in addition to the so-called local sources which have been considered thus far. These other sources of power are the great water powers of Ontario's boundary rivers.

St. Mary River

At Sault Ste. Marie the power of the St. Mary rapids is now being used to a limited extent for reducing the iron ores of the Michipicoten District. At Niagara Falls, vast quantities of power are being used for the reduction and refining of various metals. In the water powers of the St. Lawrence and Ottawa rivers, there also exist tremendous possibilities in relation to this branch of the mining industry, but up to the present time, none of the water powers capable of development in the main channel of the St. Lawrence river and none of the water powers of the Ottawa, with the exception of the Chaudiere, have been commercially utilized.

The rapids of the St. Mary's river at Sault Ste. Marie have an estimated minimum capacity of 90,000 h.p., half of which, 45,000 h.p. is available for use in Ontario. The Algoma Steel Corporation now uses about 17,000 h.p. of this power, and a project is now under consideration whereby about 30,000 h.p. will be used for the manufacture of steel and paper, and possibly also for the reduction of iron ore. The remaining 15,000 h.p. has been reserved by the Province to meet the possible industrial requirements of Sault Ste. Marie and Steelton.

The Ottawa and St. Lawrence

The utilization of any of the Ottawa or St. Lawrence water powers on a large scale would first involve the consent or co-operation of the Province of Quebec and United States respectively, and furthermore, the construction of permanent works for the proper development of these powers will, in practically all cases, be abnormally high. For this reason, unless a large percentage of the cost of these works is borne by the navigation interests, an assured market for an amount of power very greatly in excess of that now existing will be necessary to place any of these developments on a commercial footing. It is, of course, reasonably certain that an adequate market demand will ultimately develop, but how soon it is impossible to predict. The most that can be said at the present time, therefore, is that the Ottawa and St. Lawrence water powers are capable of furnishing the energy necessary for a vast output of electrically reduced and refined metal products, and when capacities of 20,000 h.p. and over on the Ottawa, and 50,000 h.p. and over on the St. Lawrence, are used in this way, the resulting power costs will compare favorably with those in any other part of the world.

The Niagara River

The present conditions in the Niagara peninsula differ radically from those outlined above in connection with the Ottawa and St. Lawrence districts.

It is, of course, evident that the costs incident to the establishment of the great power projects at Niagara Falls and on the Niagara peninsula would be comparable to those which would be involved in like establishments on the Ottawa and St. Lawrence. The question naturally arises, therefore, why these powers have not been similarly developed. The distinction lies in the fact that the Niagara projects had assured to them from the beginning the great industrial markets on the shores of the Great Lakes both in Canada and the United States. The product of these Niagara developments displaces steam power as soon as the two came into active competition with each other. The result was that the Niagara projects were able to adequately meet their annual obligations out of a revenue

[*H. G. Acres.*]

which immediately became available through the sale of industrial power. Being thus on a sound commercial footing from the very beginning of their operations, they have now reached the present height of their prosperity through the sale of power used in the immense electro-chemical and electro-thermal industries which they themselves have been mainly instrumental in creating.

These conditions led to the establishment on the Canadian side of the river at Niagara Falls of three power developments operating under franchises granted by the Commissioners of the Queen Victoria Niagara Falls Park upon the authority of the Ontario Government. Under these franchises the Canadian Niagara Power Company is allowed to develop 100,000 h.p., the Ontario Power Company 180,000 h.p., and the Electrical Development Company 125,000 h.p., making an aggregate of 405,000 h.p. Of this aggregate, one-half, or 202,500 h.p., is supposed to be available for use in Canada, when required, at a price not greater than that charged by the various companies for similar service in the United States. Of this amount, considerably more than one-half is already in continuous use in the Province of Ontario.

It might also be mentioned in this connection that the export licenses issued to the three companies above mentioned now aggregate about 213,000 h.p., so that about 11,000 h.p. is now being exported to United States which the Province has the right to call on the companies to supply when needed.

It is evident from the above figures that, in view of the rapidity of development up to the present time, the general industrial requirements of the Province of Ontario will very soon exhaust the surplus of power capable of being produced by the existing developments at Niagara Falls.

The total amount of power capable of being developed on the Canadian side at Niagara Falls is now governed by the terms of the Boundary Waters treaty, which permits the use of 36,000 second feet of water for such purposes. It so happens that when a sufficient volume of water has been set aside to permit the development of the above-mentioned 405,000 h.p. by the existing companies, a surplus of about 6,500 second feet remains, which is likewise available for the production of power. The use of this unallotted surplus, in connection with a scheme of development proposed by the Hydro-Electric Power Commission of Ontario, will produce approximately 200,000 h.p., so that at the present time, after taking into consideration the limitations of the Boundary Waters treaty and the present consumption of Niagara power in Canada and United States, it may be said that the Niagara River can furnish the Province of Ontario with 275,000 h.p. in addition to the quantity now used. Also, owing to the fact that market conditions in the Niagara peninsula are well established, it is fairly safe to state that this power could be sold anywhere east of the Welland Canal at a price not exceeding $15 per h.p. per annum, provided that power is taken in blocks of 6,000 to 10,000 h.p.

Summarizing the above, we find, therefore, that of all the water powers on the boundary rivers of Ontario, only Niagara can be considered as being an immediately available and commercial source of hydro-electric power for the reduction and refining of metals on anything approaching a large scale. It is understood, furthermore, that temperature is an important factor in some of the refining processes, so that the comparatively mild climate of the Niagara peninsula will offer a further incentive to the establishment of such industries in that territory.

Toronto, December, 1915.

Evidence of H. G. Acres and R. T. Jeffery

Mr Acres, writer of the foregoing memorandum, and Mr. R T Jeffery, electric engineer, also of the Hydro-Electric Power Commission of Ontario, appeared before the Nickel Commission at Toronto, 21st December, 1915, and gave evidence as follows:

CHAIRMAN: We have read your memorandum, Mr. Acres, and very much appreciate all the trouble you have taken in the matter. I think you fully understood the chief matters that we wished to be enlightened upon, but there are a few questions arising out of what you have written, and other questions which we should like to ask of you and Mr. Jeffery as to the arrangements for selling and supplying the power. I see you speak of the prospects in Georgian bay. You say "The canalization of this river in connection with Georgian bay canal project—that is the water power on the French river—would give us a further capacity of about 10,000 to 30.000 horse-power." Is that likely to be available before long, or what is the present condition? A. As my report states, Mr. Chairman, the availability of power on the French river depends to a large extent on the development of the canal project, and just in what stage of development that project is, I cannot say. There has been some talk of developing that particular section of the Georgian bay canal possibly previous to the completion of the rest of the project, to make North Bay a lake port, but it is hard to say when even that portion of the project may materialize. I mentioned that there is one site there that can be developed at the present time without any material aid from the canal

project; that is the site of the Chaudiere falls, which is possibly the best site on the river on account of having the storage of Lake Nipissing immediately available, but, as I have said, as that is the site farthest from the point of use, the transmission cost would be rather high.

Power Situation in Sudbury District

Q. You say that the Sudbury mining district cannot be said to be advantageously situated as regards the supply of power until this canalization is completed. You consider that is quite an important point as regards the supply of the Sudbury district? A. I do, except for what I have called production and concentration purposes. There are certain sites on the Wanapitei river which can be considered as immediately available sources of power for that class of service. They have capacities ranging from 2,000 up to possibly 3,500 horse-power, and they are within say thirty to fifty miles of the nickel producing district.

Q. And aren't any of those already taken up? A. Yes, but there are at least two undeveloped sites on the Wanapitei river which could be considered as good propositions for production and concentration. You will notice the capacity of those particular water powers is included in the 15,000 horse-power mentioned in my memorandum as being available for concentration and production purposes. Those two sites that I have mentioned are to be included in that 15,000. The rest is on the Spanish river and its tributaries.

Q. When you speak of "production and concentration," you mean what would only be done in actual mining operations? A. Work in connection with actual mining operations, that is, the drilling and taking out of ore and the mechanical work that is necessary in order to produce shipping concentrates.

Q. And, generally speaking, it looks as if, for smelting or refining, there would be a large amount of the work which would be done somewhere other than at the mine, probably in the Niagara district? Am I right in gathering that from your general remarks? A. You will notice that I have classified the various local sources of power as between those suitable for production and concentration, and those suitable for refining and production. In connection with the Sudbury district, I have stated that 15,000 horse-power may be considered as locally available for production, and concentration, and 30,000 as physically available for reduction and refining. Whether this latter quantity is commercially available or not will depend mainly upon the initial demand, not necessarily for mining purposes alone, but for any purpose which will create an adequate market for the power.

Q. It would cost practically double as much for reduction and refining as for production and concentration? A. A distinction cannot properly be made on that basis. You will note that the local sources I have set out here as having adequate capacity for reduction and refining purposes are also suitable for production and concentration.

Q. Of course. But that is not the other way? A. No, it is not the other way, if any extensive development of the reduction and refining industry is considered.

Q. How far are the Quebec sources of supply available for use in Ontario? That appears to be more or less answered in your memorandum? A. The water powers on the upper Ottawa, known as the Quinze river, are generally within 35 miles of what might be called the centre of the Cobalt mining district. I should say not more than 40 miles distant at the outside.

Q. But, then, how far are these sources of supply likely to be required in Quebec, do you think? I suppose it is only a matter of buying the current? A. I understand that most of the water powers on the upper Ottawa are now privately held for some future use, but I don't think that any specific development proposition has ever been considered, or that there is any immediate intention of developing.

Q. But the owners, I suppose, can sell it to anyone who is willing to buy, from time to time? A. Yes, they presumably have full control. They can sell all or any part as they please, that is, in Quebec, so far as present conditions are concerned.

Actual and Potential Development at Niagara

Q. I had an idea in my mind to ask whether there was any difference in the prices charged on the United States side and the Canadian side of the Niagara peninsula; that is, by the companies who produce current on either side. I mean, do the United States people sell at a higher price to Canadians than they do to their own people, and do we sell at a higher price to Americans, or is it a sort of flat rate to whoever use it? A. I think the situation there is this: On the American side the prices at which power is sold are generally higher than the prices at which Canadian companies sell it on this side, on account of the public ownership competition in Ontario. Mr. Jeffery can give you that information.

MR. JEFFERY: There is a larger market on the American side. Power is sold in Niagara Falls, U. S., at $18.00 to $22.00 per horse-power, that is 24-hour power, and you can buy it on this side at Niagara Falls up to the amount of power available for sale, of course, at about $14.50 per horse-power per year.

[*H. G. Acres and R. T. Jeffery.*]

Q. And is that difference or ratio between the Canadian and American price likely to be maintained, or will it come down to a dead level some day? A. I believe the power companies on the Ontario side have tied up, or are tying up with long term contracts, and for some time those prices will be maintained, but the amount of power they have available now, I believe, is rather limited.

Q. But all that isn't sure of use in Canada? A. No, not all of it. There is one thing, however, that might be mentioned. Our Commission or the Ontario Government has a right to demand from all these power companies fifty per cent. of the amount of power they have for sale for use in Ontario when required, the price at which this power is to be sold being the prices that are in force on the other side at points equidistant and under like conditions to what they would be if sold here. That is a stipulation that is in force now, according to a clause in these companies' franchises with the Parks Commission.

Q. Then, Mr. Acres, you mention the limit of the amount of power available from Niagara and you rather indicate that this may be increased. You speak of the amount being limited. "It is evident from the above figures," and so on, "the industrial requirements of the Province of Ontario will very soon exhaust the surplus of power capable of being produced by the development of Niagara Falls." A. Yes. That confirms what Mr. Jeffery has said.

Q. Then you state "It may be said that the Niagara river can furnish the Province of Ontario with 275,000 horse-power in addition to the quantity now used?" A. Yes.

Q. That would be a very big increase. When would that be possible? A. In view of the market conditions and the market prospects in the Niagara peninsula that quantity of power is not as large as it looks. It won't take many years to absorb that power even without the establishment of new industries, having in view only the normal extension of the existing industrial requirements of the Province and the enlargement of existing industries.

MR. YOUNG: Does that involve the whirlpool scheme? A. That involves the new proposition, by which the Commission proposes to develop 200,000 horse-power, which is all the power that could be considered still available from the amount of water that has been allotted to Canada under the Boundary Waters treaty; that is under the present conditions of use and under the terms of the treaty.

Comparative Cost of Northern and Southern Power

DR. MILLER: I would like to ask Mr. Acres if, in view of the fact that the power that is now developed at Niagara is limited, and practically all taken up, and they are starting this coal plant at Buffalo, also considering what he has just said about this 275,000 horse-power not representing as much as it might seem on account of the demand in that district, whether it is not likely that cheaper power for refining might be had in the north; there wouldn't be so much demand there for it? Probably these French river powers or powers like the Quinze river in Quebec may not be all taken up for years to come, and a consumer might get a supply considerably cheaper than in the Niagara district? A. That might be true, in some instances.

CHAIRMAN: What would be the transportation facilities in such a district for getting the material from the mines and for taking away the refined nickel?

DR. MILLER: Wouldn't that be easy; just as simple as down here? Because if you shipped it down here you would have to ship the anodes and refine it and then ship it on; but I have looked at that French river power as a great asset for the Sudbury district. It would seem to me it is very important up there? A. Yes; the commercial feasibility of developing the French river power simply depends upon the initial demand and its subsequent rate of increase. If you could locate a mining industry in that district capable of absorbing 10,000 horse-power within a reasonable time, power from the Chaudiere site could be supplied quite cheaply.

Q. A third company is beginning operations at Sudbury. The question of a larger supply of power is important, especially for them.

CHAIRMAN: And would the cost from the French river be less or greater than that from Niagara? A. It might be greater, taking the Chaudiere site by itself, because the delivery of 10,000 horse-power from the Chaudiere to any established point of use would possibly, on account of unfavourable conditions as regards transmission, cost more than Niagara power supplied locally in the Niagara district. That is, supplied anywhere east of the Welland canal, as I mentioned.

Q. But not very much more, I suppose? A. There wouldn't be a very great difference. If it were at any time possible to absorb the whole capacity of the French river development for industrial purposes anywhere along the line of the C.P.R., I don't imagine that the 30,000 horse-power developed and delivered, including all transmission charges, would cost more than the prevailing prices existing now in the Niagara peninsula, but they might be higher for the initial 10,000 horse-power. The whole question of the supply of cheap power from the French river depends on the initial demand. I should say that even without the help of the

Canal works, an assured market for 30,000 horse-power in that district would make possible the successful development of the French river powers at prices which would compare reasonably with the prices that now obtain in the Niagara peninsula.

DR. MILLER: Then, as the demand goes on in the Niagara district, isn't it likely that private companies, at least, will be charging higher prices; their prices may rise in the future owing to the great competition? A. I imagine that Government control and the influence of public ownership would be likely to prevent that. Possibly Mr. Jeffery can discuss that point better than I can.

Q. I think some of them told us over there that they were selling power too cheaply?

MR. JEFFERY: They have a number of long term contracts. I believe they have one for 7,000 or 8,000 horse-power in Port Colborne for about $9 per h.p. That contract was made before the Hydro Commission got their contract with them, and when they had a large amount of power for sale and no market, and consequently they accepted almost anything they could get and signed up a ten year contract with a company in Port Colborne at about $8 or $9 per h.p., but I know that will not continue. However, there are some exceptional cases, and it is quite possible that the private companies will be able to furnish a certain amount of power at a good figure, provided our Commission don't get a large block of power for sale and compete with them. If we get that large block of power I believe we will hold them down, and they will have to sell at about the same price as they are now selling at.

MR. ACRES: Of course, any statements I have made are based on the previously mentioned prices in the Niagara peninsula, namely, from $14 to $16. When I made these statements I did not take into consideration any special prices such as Mr. Jeffery has just mentioned.

Power Costs in Ontario and Elsewhere

CHAIRMAN: Now, could you tell us whether there are any places in the United States where electric power is much cheaper or any cheaper than at Niagara?

MR. JEFFERY: I have been looking up our records I didn't have very much time unfortunately. The cheapest power I believe that is sold in the States is in California. One of our engineers was down there and travelled through California this summer, and he visited nearly every power plant and practically every sub-station on the whole Coast district to get information about their engineering and construction. While there he got considerable information about the rates they were charging for power, and when you hear those rates you will think, I believe, that the rates in Ontario are very, very low. The Pacific Coast and Electric Company of San Francisco have large water power plants situated, I believe, some distance back in the hills. They have a number of plants all connected, and their rates for twenty-four hour power are from $30 to $40 per horse-power per year. The Pacific Light & Power Company of Los Angeles, who also have a number of power plants I believe similarly situated, are also selling for about the same figure, $30 to $40. The Southern Sierras at Riverside, California, sell power at $40 to $50 per horse-power per year. The Mount Whitney Power Company—it is rather a small company when compared with the others—also sell power at from $40 to $50. The Pacific Light and Power Company, who have a number of plants in Washington and Oregon, are selling 24-hour power for $48 per horse-power per year. Now, I think—

MR. YOUNG: Excuse me, just there Have you got the transmission distances for those companies? A. These vary anywhere from 50 to 100 miles; some of them less than that.

Q. And what sort of country? A. It is a hilly country, and a good bit of it is rather rough.

Q. Mountainous? A. Yes.

CHAIRMAN: Those prices you quoted are prices delivered? A. Yes.

Q. The company building the transmission line itself? A. Yes.

Q. Do any of those companies you have just mentioned produce their power from burning coal, or are they all water power companies? A. These are all water power plants.

MR. ACRES: I might say that practically all these companies have auxiliary steam plants to take care of peak load and to tide over periods of water shortage. The operating expenses of these steam plants are included in the cost of power.

Q. The reason I mention that, is because in Newcastle, England, we get power there from slack coal at one-eighth of a penny per kilowatt per hour, which comes to between $16 and $17 per horse-power per year, and it is the cheapest in England. It is wonderfully cheap, and, of course, it is actually cheaper than some power in this country. You said you might be able to give us some prices as to power produced by burning fuel in the States, which is bound to increase, I should think?

MR. JEFFERY: Yes. I have a number of records of rates here which I was not able to get in very good shape. They are all tabulated for the different companies, but unfortunately I haven't got them worked out in the cost per horse-power per year, and that is practically the only way of comparing their rates. I have all their rates here but they are in kilowatt hours.

[*H. G Acres and R. T. Jeffery.*]

Q. Could you let us have this in the form of a memo later on? A. Yes, I could. I have Buffalo, Shawinigan and Chicoutimi in Quebec—they are selling power for $20 there—and Chicago, Cleveland, Toledo, etc. I have a long list here I could put in the form of a memo, and I will make that up in cost of horse-power per year, because from these rates per kilowatt hour, you would not be able to see through them without quite a little computation.

Q. Then there is a limit beyond which, of course, electric power cannot be produced except under the very best of conditions. Now, could we get some idea from you of the absolute limit, the lowest limit at which power can be produced? One hears a man say that he is going to produce power and sell it at $4 and make a profit. Now, there must be a limit, and the thing becomes impossible. Can you give us some ideas as to the lowest prices at which electric power could ever be available? A very rough limit perhaps?

MR. ACRES: In connection with that, I should say that in this country the fixed charges on capital investment alone would in almost every case amount to the sum you have named, $3 to $4 per horse-power. The average would be higher. It would only be under almost unique conditions that a project could be properly developed with a resulting fixed charge of less than $3 to $4 per horse-power per annum.

Q. So prices of that kind would be simply impossible? A. I should imagine so, in Ontario anyway, speaking from what knowledge I have of the charges involved.

MR. GIBSON: Have you the cost, or any information as to the cost, of electric power in Europe? A. No, none that I could give off-hand. A certain amount of such information could be obtained without much trouble. Power can be produced in many places in this country for $8 or $9 per horse-power per annum; that is power at the generator switchboard. No transmission or transformation costs are included in such figures.

DR MILLER: So many people tell us New York and New Jersey are the only places where refining can be done in America? A. I had one of the engineers in the office figure out approximately what power would cost in Boston, and his figure was ridiculous—I didn't have time to check it—$215 per horse-power per year. That is practically the lighting rate in Montreal. At Messina, power is being sold for $12 at the plant, plus transmission line charges, which amounts to approximately $20. Practically all the companies are amalgamated now so that the price would be fairly general in the Montreal district. In Winnipeg, where they claim they have very cheap power, the list rates for anything over 50 horse-power, are $39.20. Whether they give a discount for large blocks of power, I don't know.

Hydro-Electric Commission Schedule of Charges

MR. GIBSON: In Toronto, what is the rate for power? A. Well, the rate or rather the cost per horse-power in Toronto varies, depending on the use of the power. The rates in the municipalities of Ontario are differential rates depending on the number of hours used, and it may vary, as you will understand. I have curves here. These curves are rather confusing to one who has not been used to them, but here is a rate curve, the ordinate is dollars per horse-power per year, the base is hours' use per month of connected load, or maximum demand. Our rates in all the municipalities are based upon a certain rate for the first 50 hours' use per month, of connected load or maximum demand, a lower rate for the second 50 hours' use, and a very much lower rate for all over that amount per month, plus $1 per month per horse power per month of connected load. These are complicated, but the whole of the curves figure out, in dollars per horse power per year, and, as I said before, in hours' use per month. Starting with the net service charge per h.p. the first step of the curve is fairly steep, the part for the second 50 hours' use runs up at a somewhat less angle, but after the first 100 hours' use it drops off and is quite flat. The long hour users pay more for their power than the short hour user per horse power per year. His cost per kilowatt hour, or the unit of current consumed, however, is very much less. Now, the rate that our Commission would give for any large company doing smelting work, would not be based on those rates. It would be a flat rate. We are selling power to the Union Carbide Company in Welland or very close to Welland, at 46,000 volts for $14 per horse power per year. They use about 16,000 horse power. We are selling about 1,400 horse power off the same line, or an extension of the same line, to the Electric Steel & Metals Company for $15.72, and we are just proposing to make a contract with a zinc company in Welland who are experimenting with a process of reducing zinc electrolytically at $15 to $16 per h.p. They propose to use 5,000 horse power, and are bringing the raw material from Quebec, past Montreal, where they have cheap power, and propose reducing it at Welland.

Q. Is that what is called the Weedon Company? A. Yes, the Weedon Mining Company. This is their new branch which they call the Zinc Company of Canada, and they will get power in Welland at about $15. I just forget what it is, but it is less than $16. But our rates in municipalities will not be the same schedule or the same class of rates that we would give for a large company. To large companies we would give flat rates.

CHAIRMAN: Is this information provided in your curve sheet? A. No, it is not.

[H. G Acres and R. T. Jeffery.]

Q. It would be rather useful to be attached. A. According to the base rate it is $1.00: 2.9; 1.9; 0.25, for a $31 base rate. This gives the base rates. You can follow them there.

MR. ACRES: Mr. Jeffery did not mention that that schedule of differential rates applies only to blocks of power not exceeding about 1,500 horse power, and for your purpose that schedule of rates might not have much bearing, because as Mr. Jeffery has said, when the Power Commission received a request for a block of anything over 1,500 to 10,000 horse power, it is considered a specific proposition by itself; and it is a matter of our wholesale price of power plus the cost of transmission service to the consumer.

Q. Still, if you could let us have a schedule, I think we should like to have it, because there are a good many small concerns requiring power. A. There is no reason why you should not as long as you appreciate its limitations, but it would be very misleading to imagine that 10,000 horse power would cost what that rate curve indicates.

MR. JEFFERY: I might say, by the way, we have been making up our rates on the basis of these three kilowatt-hour rates, being in the ratio 12, 8 and 1, and while that has worked out all right where the cost of power is low, when you get to the point where power costs you $35 and the follow-up rate becomes decimal three or decimal four cents, the angle of the curve is too high and we have to cut them, and we are now making a maximum third rate to all municipalities of 0.15 cents per K.W.H.

Q. Does that mean you are going to modify this rate? A. Yes.

MR. YOUNG: What you will hand in to the Commission will be a corrected sheet? A. Yes.

Cost of Stepping Down

CHAIRMAN: There is one point that I expect you have fully realized as regards the use of current for electric smelting and electrolysis. It is of very low voltage. Now, we will say to smelt matte, or something of that kind, would probably require 100 volts, perhaps 200, but it is very likely to be 100 or less. When it comes to electrolytic refining it may be four volts or even down to two or less—that would be transformed at the place of use—would it make much difference, or what difference would it make, in the cost if the customer should buy it from you and transform it? Could you give us any idea as to the ultimate cost? Suppose a man bought at $20, say 12,000 volts, or whatever you supply? By the way, is that figure reasonably correct? A. Well, it is a reasonable figure for small blocks. In fact, the Ontario Power Company are selling now practically all of their power in Welland at that voltage; 12,000 volts is too low to transmit power for any distance in large quantities. Our voltage in the Niagara district for large blocks of power is 46,000 volts. The Union Carbide Company buy power at 46,000 volts and step it down in their own transformers, which are units from four to five thousand kilowatts each. The full load efficiency of a large transformer of that size is from 98 to 99 per cent. They will lose in these transformers approximately 1½ per cent. This will vary somewhat, depending on the load on the transformers. If they are fully loaded the efficiency may be as high as 99 per cent. Then, in addition to that they would have to add on capital charges on the equipment that they have to instal, which will cost anywhere up to $3 a kilowatt installed, perhaps not that high; and then you have to add on about 10 per cent. of the capital cost of this transformer to the cost of power.

MR. YOUNG: Would that be about 10 per cent. on your horse power per year? A. You take a transformer of 5,000 kilowatt capacity costing $3 per kilowatt; the cost of that transformer is $15,000; 10 per cent. is $1,500 of capital charges. That is the interest and depreciation that you have to allow on that equipment; $1,500 spread over 5,000 horse power is about 30 cents added on to cost of power for capital charge.

CHAIRMAN: That is quite small. A. It is small, and then your losses about 1 per cent. on to that would be another very small item.

MR. ACRES: That would be 50 horse power, costing about $90 per annum.

MR. JEFFERY: We figure it costs about $1 per horse power to step down.

Q. Is that the same whether you are using direct or alternating current? A. No.

Q. For electrolytic work it must be direct current? A. In Welland practically all of their smelting is done by the electric arc. They have a number of furnaces which operate at 80 to 100 volts; they are nearly all A.C. furnaces.

Q. Yes, but when we come to electrolytic processes such as deposition of metals or making alkali, then it has got to be direct current? A. You have then got to put it through a converter. You have got to change it from alternating to direct, and your losses in that case are very much larger.

Q. And the only way then, is to use a transformer consisting of what we call a motor dynamo? A. Yes.

Q. That would add, probably, another 10 per cent.? A. It would be higher than that. The efficiency of that unit would drop to between 85 and 90, I would say, or 85.

Q. In England we generally consider we lose 15 per cent.? A Well, it is approximately that.

MR. ACRES: Another point to consider is that these converters would be of a very special design in view of the low D.C. voltages.

[*H. G. Acres and R. T. Jeffery.*]

MR. JEFFERY: And the capital cost of those is high. You have two units to take care of for each block of power. Then for 5,000 kilowatts you have a generator and motor as well as a transformer, because you can't get a motor to operate at 46,000 volts; you have to step down to 2,200 volts or some commercial motor voltage, so that to get the direct current it would cost you very much more than the alternating.

Q. Can we say then that the total additional expense of stepping down from high voltage alternating current to low voltage direct current, would be a total of 25 per cent., or not more than 25 per cent.? A. Well, that would depend on the cost of the power, because it is such a large item; you lose 15 per cent. in machine losses and then you have the capital charges added on.

MR. ACRES: I should say a better way to express it would be to say that the increment of cost to be added to the delivery price of high tension power would be approximately 25 per cent. of the capital cost of the equipment necessary to step down and convert the current. That is subject to correction, but I should think it would be fair. The capital cost on which that 25 per cent. is based would be the capital cost of the transformer installation, and the capital cost of the converter installation, plus switching. A charge of 25 per cent. on that capital cost would be a lump sum of annual charges to be added to the total annual cost of high tension power.

MR. JEFFERY: In the motor generator you have losses about 15 per cent. Then, you have capital charges on equipment to add to that. It will run to 25 per cent.. That figure wouldn't be very far out.

MR. YOUNG: Let me understand that, because I like to get these things in accurate form. Now, supposing the price on your scale to the consumer is $30 or say, $20. A. Yes.

Q. Then, in order to supply refining works, as the Chairman has explained, are you to add 25 per cent. to that $20. How much would that be?

MR. ACRES: That is not quite the situation. The 25 per cent. referred to is not 25 per cent. of the annual cost of delivering the high tension power. It is 25 per cent. of the capital cost of the additional equipment. That 25 per cent has no relation to the actual cost of the power that has been mentioned in these records.

Q. No. What I was trying to get at was from the standpoint of the man who is going to operate a refining plant? A. You have two factors coming in there. One is the cost of high tension power and the other is the annual charge incident to the installation and operation of transforming and converting equipment.

MR. GIBSON: Does the cost of equipment vary much? A. It is hard to say what the cost of the equipment would be for voltages as low as have been mentioned.

MR. JEFFERY: It would run at least $15 to $20 a kilowatt.

Q. That is the capital? A. Yes.

Q. So that you think the additional charges, based on the cost paid for the current, might perhaps go over 30 per cent. Would it be safe to add one-third as a maximum, do you think? A. Oh, yes, that would be the maximum, I am sure.

CHAIRMAN: Even that figure would be useful to us. A. I think we would be almost safe there to take $20 a kilowatt as the cost of installation. Now, suppose we take that on 5,000 and just figure that. For 5,000 kilowatts would be $100,000; 10 per cent. of that is $10,000, so dividing $10,000 by 5,000 there is $2 a kilowatt added for capital charges. There is $2 then: you have 15 per cent. loss also to add.

MR. ACRES: Which is 750 horse power multiplied by the base price of power, which you have taken at $14.

MR. JEFFERY: Yes, $10,500, to which would have to be added the previous total of $10,000, making a total of $20,500, covering the annual fixed charges and power losses on 5,000 kilowatts. That would be $4.50. I will include a statement of that in my memo; $4.50 added to $14 power to take care of the losses and capital charges on the D.C. and A.C. equipment.

CHAIRMAN: Yes; that would be almost exactly 33 per cent. In other words, it would be 25 per cent. of the total cost? A. Yes. But I will go into that in detail when I get back and make you a statement and embody it in the memorandum.

Physical Conditions in Ontario Good

MR. GIBSON: Mr. Acres, are there any fundamental disadvantages connected with the development of water power in northern Ontario, that are not found in other countries or climates?

MR. ACRES: I don't think there are. The only disadvantage which might be called a fundamental disadvantage, that is as compared with southern territory, is the question of ice trouble.

Q. That is in the generation of power and the operation of water wheels? A. Yes. Troubles of that kind are being very largely overcome by modern methods of construction. It is only in the older plants that any serious trouble is experienced with ice at the present time, except in very exceptional cases.

[H. G Acres and R. T. Jeffery.]

MR. YOUNG: Well, that is almost negligible under modern conditions? A. Yes, it would be in the case of a large water power such as a Commission of this kind would be interested in.

MR. JEFFERY: A small water plant is liable to cause trouble where you have rapids above the plant; ice forms on the rocks and flows down, causing trouble. Where you have still water, you have practically no ice trouble at all.

MR. GIBSON: What is the limit in distance to which power can be transmitted?

MR. ACRES: There are only two factors that govern that. These are the available market at the end of any given transmission line, and the amount of money that it is economical to expend in line construction.

Q. What would you consider would be the maximum transmission loss that would be permissible in operation? A. I think that the losses that have been permissible in the Power Commission's construction are in the neighborhood of 10 per cent.

MR. JEFFERY: We are transmitting power to Windsor from Niagara Falls, 100,000 volts, 250 miles. The cost of the power, of course, varies in the municipalities along the line. The 4,000 horse power rate in Windsor from Niagara Falls is $38.

Q. And what do you regard your loss en route to Windsor? A Approximately 10 per cent.

Q. You could transmit it farther with a greater loss? A. Yes, by a large aluminium line.

MR. ACRES: You could double the distance with the same loss, provided you put sufficient capital investment into the conductors. Line loss is purely a matter of dollars and cents.

DR. MILLER: Would power be available from the upper Ottawa for refining and other industries in Sudbury? A. It would from a physical standpoint.

Q. That would be 125 miles from Sudbury? A. Yes, I should say it would be at least that.

Aluminium vs. Copper for Transmission

CHAIRMAN: Am I right in thinking that you generate your current at 12,000, then step it up to whatever is necessary, 100,000—or I heard 200,000 spoken of—in order to be able to use thinner conveying wires and that 200,000 is about the maximum; what would you use to go this long distance of 150 or 200 miles?

MR. JEFFERY: Well, we use 110,000 volts now. Our Power Commission standard is 110,000 volts. I believe there are one or two companies in the States which are using as high as 150,000, but that is where the climate is somewhat drier than ours, and their atmospheric conditions are a great deal more advantageous for transmitting at that voltage. The voltage that is used for transmission, that is the economical voltage, depends on the amount of power and the distance you have to transmit. In the eastern part of Ontario they have a system operating at 44,000 volts; in Winnipeg they transmit at 66,000 volts. The amount of power that can be transmitted economically a given distance depends on the voltage that you are transmitting at, and the size of copper or aluminium cable is varied to give the permissible line loss; in other words, you may either put in larger aluminium cable, or duplicate the lines, or put three or four; depending upon the class of service and operating conditions required to be met.

Q. And the losses, I suppose, are heavier with the higher voltages? A. The higher the voltage the less copper or line loss you have. That is why we increase our voltage to decrease our line loss. The high line voltage is used to decrease the transmission loss on the lines.

Q. I was under the impression that the high voltage was merely because you could use thinner conductors and save in metal? A. Well, it is that way, too, but the economical condition regulates the voltage at which power is transmitted. If you use smaller conductors and higher voltage, you must use more expensive apparatus and more costly lines to take care of it. That is you have got to have more expensive and larger insulators. If you wish a smaller line or a lower voltage for the same amount of power, you can use a cheaper line, that is as far as the insulating qualities go, but with a lower voltage and transmitting the same amount of power you must use a larger conductor.

Q. Thicker wire? A. Yes, to get the same loss.

MR. GIBSON: You were speaking of aluminium and copper; do you use both for conductor wires? A. Well, we use either, depending on economical conditions or the market value of aluminium or copper.

Q. How does aluminium stand the climate in Canada? A. We have no trouble at all with it. We have found that aluminium, if strained too tightly, will stretch under severe storm conditions beyond its elastic limit and would have to be changed. You have to be careful with it and not stretch it too tightly, but we use now, on our high tension lines, reinforced aluminium with a steel core and it is giving very good satisfaction.

CHAIRMAN: You don't use aluminium alloys for the purpose? A. No, we use practically the pure aluminium.

MR. GIBSON: Is it not tending to displace copper to some extent? A. It is. Practically all our extension lines are aluminium, but war conditions have raised the price of aluminium to over 50 cents per pound, where it was 26 or 28 cents, and we cannot buy it now at all. Fortunately we had an order ahead of half a million pounds, and it has helped to tide us over.

CHAIRMAN: In England we had great difficulty in the early days, it simply wouldn't stand the corrosion. A. Well, of course, we haven't got to meet those conditions.

[*H. G. Acres and R. T. Jeffery.*]

Q. Yes, but they will be present in Sudbury, I suppose? A. Well, I don't know; of course, in Sudbury they have quite a lot of sulphur there; it might affect it.

Q. Aluminium is much purer than it was? A. Yes.

DR. MILLER: There is quite a difference in sleet storms? A. I have yet to see an aluminium line with sleet sticking to it. I believe we have some lines where sleet does stick to it, but when a line is in operation with anything like a load on it, it won't stick to the aluminium. I have never seen any sleet stuck to the Electric Power Company's lines which are east of here.

CHAIRMAN: That is aluminium or copper? A. Aluminium. It sticks to copper, but it doesn't stick to aluminium. I have seen copper lines with sleet on them three inches thick.

Powers on the Lower Ottawa

MR. GIBSON: Mr. Acres, have you gone into the question of the availability of those powers on the Ottawa river below Lake Timiskaming?

MR. ACRES: The situation there is rather complicated by the joint jurisdiction of the two Provinces.

Q. Quite so; but apart from that question? A. From a physical standpoint there are some very valuable water powers on the Ottawa river, and the only discounting factor is the question of available market. None of the Ottawa river water powers could supply power at prices comparable with those at which power is supplied in other parts of the Province, unless a market of at least 20,000 horse power were assured from the outset, because the capital cost of permanent works there is very high. For instance, at Chats Falls, the dam which would be necessary to properly develop the power there would be immensely expensive, and the fixed charges on the capital cost of the dam alone would amount to several dollars per horse power, even on the basis of 20,000 horse power sold, so these powers are not susceptible for commercial use until markets of that magnitude are available.

Q. Has not the dam at the foot of Lake Timiskaming a beneficial influence on the whole question of water power on the Ottawa river? A. It will ultimately, as soon as a proper system of regulation has been devised.

Q. And has there been considerable water power created at the foot of Lake Timiskaming by the dam? A. No. The Timiskaming dam is a regulating dam. At certain times of the year the Timiskaming dam will maintain a head of water of perhaps 20 feet. At certain other times of the year it may not be more than three feet. It is a regulating and storage dam.

CHAIRMAN: Referring to your memorandum, Mr. Acres, and Mr. Jeffery having dealt with the topographical conditions, the transmission distance and the available capacity of the water powers in Ontario, and the other factor—the available market; assuming we have the market in the refining of nickel-copper mattes for a large quantity of power, what would be the position in Ontario as compared with other places for that industry? A. In connection with that question, it has been covered in a general way on the last three pages of my memo. Now, that is as far as one can go, if the question of market possibilities is considered. If you can develop a smelting industry requiring 20,000 horse power, you can get cheap power from the Ottawa river. If you can develop a smelting industry requiring 50,000 horse power, you can use the St. Lawrence. You will understand that this statement is made without regard to difficulty which might arise through interprovincial or international jurisdiction on these rivers.

MR. YOUNG: Yes; then supposing they wanted a lot of power in the Sudbury district, from where can you give it to them? A. From the French river or the Ottawa.

Q. Practically the bulk of power in the Sudbury district is made use of? A. Yes, with the exception of the French river. I have estimated that there is about 15,000 horse power still available at the various undeveloped sites, some not very good from a development standpoint; some of them very good.

MR. GIBSON: That would hardly be a practical source of power? A. It could be only considered a source of power for the practical operation of mines and concentration. I have mentioned the fact, which I think is right, that no power of less than 10,000 horse power ought, as a rule, to be considered suitable for reduction and refining purposes. There are no such powers in or available to the Sudbury district except those on the French river and the Ottawa river. Apart from these 5,000 horse power is about the limit of capacity for the undeveloped sites.

Q. You mentioned two powers of the Wanapitei as not being utilized. Are those above or below Lake Wanapitei? A. Both are below.

Q. Where are they? A. One is near Stinson Station on the C.N.R.

Q. And the other lower down? A. Yes, near the mouth of the river.

Q. How much is used now at Sault Ste. Marie? A. Nearly 20,000 horse power out of a total of about 45,000 available. I think that is mentioned in my memorandum in connection with the water powers of the Boundary rivers. I should add also that the 20,000 horse power now developed is mostly used in connection with the steel industry and the manufacturing of pulp and paper.

[H. G Acres and R. T. Jeffery.]

Letter from Mr. R. T. Jeffery to Ontario Nickel Commission

The following letter supplementing the evidence of Mr. R. T. Jeffery as given above was addressed by that gentleman to the Commission 16th February, 1916:—

"I regret very much that through rush of work and an attack of la grippe, I have been unable to forward you, at an earlier date, the information arranged for some time ago at your meeting.

"Since that time we have been collecting considerable data regarding rates at which power is sold by various companies in different parts of the United States. We have as yet been unable to obtain very much information in connection with the selling price of power in other countries, but hope to have more information along these lines in the near future.

"On the attached sheets is given a list of power companies and municipalities, showing the rate per horse power per year at which these companies and municipalities are selling power, based on 24-hour operation and 10-hour operation per day, with a load factor in each case of 85 per cent. In practically all of these cases the rates which we have on record, in connection with power sold by these companies and municipalities, are stated in cents per K.W.H., with, in a great many cases, a service charge per month, and with these rates as a basis, we have calculated the cost of 500, 1,000 and 2,000 horse power operating six days per week, under the above-mentioned conditions.

"As already stated, power can be purchased from our Commission in the Niagara district at a price of $14 to $16 per horse power per year, and, while the 100,000 horse power for which our Commission have a contract with the Ontario Power Co., is practically all used up, we have at present an additional contract with the Toronto Power Company for approximately 16,000 horse power, and have practically completed arrangements with the Canadian Niagara Company for an additional block of power at approximately $13 per horse power per year, and our Commission expect, at the next session of the Ontario Legislature, to apply for authority from the Government to proceed with the preliminary work in connection with a power development at Niagara, which development will have a primary capacity of 100,000 horse power, and an ultimate capacity of approximately 600,000 horse power

"In addition to power at present available, as above set out, the franchises of the Ontario Power Company, the Electric Development Company and the Canadian Niagara Company at Niagara Falls provide that, if the power which they are at present developing on the Canadian side, and transmitting to the American side for consumption, is required in Ontario, this power shall be supplied at figures equivalent to prices at which these companies are selling power on the American side at points equally distant from the source, and under similar conditions.

"The clause referring to this matter is given in the following paragraph of these agreements:—

'The Company whenever required shall, from the electricity or pneumatic power generated under this agreement, supply the same in Canada to the extent of any quantity not less than one-half of the quantity generated at prices not to exceed the prices charged to cities, towns and consumers in the United States at similar distances from the Falls at Niagara for equal amounts of power and for similar uses, and shall, whenever required by the Lieutenant-Governor in Council, make a return of prices charged for such electricity or power, verified under oath by any chief officer of the Company, and if any question in dispute arises involving the non-supply of prices of electricity or power for consumption in Canada, the High Court of Justice of Ontario shall have jurisdiction to hear and determine the same and enforce the facilities to be given or the prices to be charged.'

"On another sheet the writer has tabulated the average cost per K.W. of large transformers for stepping down high tension power to a voltage at which this power would be used for furnace or motor work. On this sheet is also given the average cost of motor generator sets and rotary converters for changing A.C. power to D.C. power for electrolytic work.

"On this sheet is also given the average percentage losses in transforming current from high to low voltage, and also the losses in motor generator sets.

"I am enclosing a copy of a print showing our standard schedule of differential K.W.H. power rates as given for power supplied at certain definite figures per horse power per year."

[*R. T. Jeffery.*]

Electric Power Costs in American Cities

Company or Municipality.	Cost per H.P. per year, 24-hour power, 85 p.c. L.F., 6 days per week.			Cost per H.P. per year, 10-hour power, 85 p.c. L.F., 6 days per week.		
	500 H.P.	1000H.P.	2000H.P.	500 H.P.	1000H.P.	2000H.P.
Western United Gas & Elec. Co., Illinois.	72.75	72.75	72.75	58.04	58.04	58.04
Munroe Electric Co., Wisconsin.........	118.80	118.80	118.80	70.80	70.80	70.80
Springfield Gas & Elec. Co., Springfield, Missouri	97.00	97.00	97.00	83.45	83.45	83.45
Cleveland Illuminating Co., Cleveland, Ohio	49.15	H.T. 36.93 power	H.T. 36.93 power	32.90	25.60	25.60
Edison Elec. Illuminating Co., Boston..	67.70	67.30	67.00	32.95	32.50	32.30
Pittsburg, Penn........................	41.10	34.65	31.50	27.20	20.80	17.60
Incuman (Argentine)..................	162.00	161.30	161.20	67.50	67.40	67.30
People's Incandescent Light Co., Meadville, Penn..........................	71.00	71.00	71.00	29.84	29.84	29.84
Utah Power & Light Co	54.37	50.05	47.89	54.37	27.20	25.05
The United Illuminating Co., Bridgeport, Connecticut..........................	95.20	95.20	95.20	40.00	40.00	40.00
The Evansville Pub. Service Co., Indiana.	83.36	82.00	81.00	45.00	44.00	43.00
Erie County Electric Co	114.00	....	....	59.12	....	....
U.S. Reclamation Service on the Minidoka Project, State of Idaho	46.47	....	....	29.74	....	....
The Merchants Heat & Light Co., of Indianapolis, Ind.....................	58.65	....	....	30.97	....	....
City of Leeds, England.................	41.83	....	....	20.67	....	....
Duluth Edison Elec. Co	113.90	....	....	47.48	....	....
Detroit Edison Co., Detroit	37.45	....	....	31.40	....	....
" " 4,700 Volts	32.58	....	....	29.89	....	....
Buffalo General Elec. Co. Effect Sept. 1. 1915................................	59.45	59.41	59.30	31.76	31.72	31.72
New Orleans Railway & Light Co......	53.05	49.26	48.37	31.35	30.69	28.68
The Edison Illum. Co., of Boston........	43.55	31.89	29.80	22.66	18.05	16.36
Indianapolis Light & Heat Company....	58.67	....	....	30.97	....	....
New York Edison Co.................	101.42	....	....	57.71	....	....
Omaha Electric Light & Power Co., Omaha, Neb	38.74	30.24	29.89	24.90	20.69	18.30
Texas Power & Light Co., Dallas, Texas	36.00	31.82	27.45	23.70	19.32	17.12
Pacific Power & Light Co., Portland, Oregon	75.40	....	....	43.20	....	....
Berlin Pub. Service Co., Wisconsin......	240.00	....	....	136.00	....	....
The Springfield Gas & Electric Co......	67.50	....	....	40.00	....	....
Pasadena, California	133.20	....	....	64.20	....	....
Southern California Edison Co., Los Angeles	46.51	46.51	46.51	19.39	19.39	19.39
Portland Railway, Light and Power Co., Portland, Oregon	37.50	34.46	32.94	24.08	22.01	20.49
Winnipeg.............................	35.66	32.66	31.16	23.47	20.47	18.97
Calgary	53.20	52.71	52.47	22.73	22.25	22.01

[R. T. Jeffery.]

Electric Power Costs in American Cities

Company.	Cost per H.P. per year, 24-hour power, 85 p.c. L.F.			Cost per H.P. per year, 10-hour power, 85 p.c. L.F.		
	500 H.P.	1000H.P.	2000H.P.	500 H.P.	1000 H.P.	2000H.P.
Philadelphia D.......	118.70	Same	Same	64.30	49.45	Same
" E.......	90.20	"	"	60.72	40.75	or less
Boston D............	76.00	"	"	53.40	35.20	"
New York...........	116.00	"	"	57.40	49.45	"
Washington E........	76.00	"	"	48.90	33.10	"
Minneapolis..........	69.80	"	"	41.50	31.30	"
Baltimore S.........	69.80	"	"	45.90	31.30	"
Milwaukee Std.......	63.30	"	"	41.90	28.25	"
Cleveland, Wholesale.	52.20	"	"	37.20	24.15	"
Providence G........	52.20	"	"	30.68	22.75	"
Chicago C...........	63.30	"	"	41.90	27.65	"
" C..........	57.00	"	"	39.56	26.10	"
Buffalo..............	72.65	"	"	47.80	33.70	"
Cobalt...............	54.72	....	....	30.20	....	....
	198,000 KWH	....	....	82,500 KWH	165,000 KWH	....

Cost of Transforming Current for Smelting

Cost per K.W of large transformers, designed for stepping down power from approximately 45,000 volts to a voltage suitable for motor or furnace work:—

1,000 K.W..	$3.25 per K.V.A.
2,000 K.W..	2.75 per K.V.A.
3,000 K.W..	2.25 per K.V.A.
5,000 K.W..	2.00 per K.V.A.

Efficiency:

	¾ Load.	Full Load.	1¼ Load.
1,000 K.W............	98.1 per cent.	98.2 per cent.	98.1 per cent.
2,000 K.W............	98.4 per cent.	98.5 per cent.	98.4 per cent.
3,000 K.W............	98.4 per cent.	98.5 per cent.	98.4 per cent.

It will be seen from the above figures that a 3,000 K.W. transformer will cost approximately $6,750, and the losses on these transformers, when operating at full load, will be approximately 1½ per cent., or 45 K.W.

Cost per K.W. of rotary converters or motor generator sets will vary from $12 to $17 per K.W., depending on the size of the unit used, as well as other local conditions.

The efficiency of motor generator sets of large size, when operating at full load, is approximately 83 per cent., so that the losses on a 3,000 K.W. motor generator set, when operating at full load, would be approximately 610 K.W.

[E. T. Jeffery.]

SECTION G

HYBINETTE ELECTROLYTIC PROCESS OF REFINING

Evidence of Mr. V. N. Hybinette, of Kristianssands, Norway

(London, England, 4th April, 1916.)

CHAIRMAN: I was wondering whether you could start by giving us some little description of your earlier connection with the nickel industry and the different companies—the work at Missouri, for instance, and the International? A. I told Dr. Miller and Mr. Cochrane the story of my connection with the nickel business some years ago.

DR. MILLER: I wish I had had it taken down then.

Early Days in Scandinavian Nickel Industry

CHAIRMAN: Perhaps now is an opportunity of getting it again, because it is interesting and important to us. A. It may seem to you at the beginning that I am taking you too far back, but to show you just how it all came about, I shall start at my old home town, Falun, in Sweden. There they had what were in olden days the largest copper mines in the world. About 1875 they stopped their old smelting business, and introduced the Henderson process of chloridising roasting and leaching for their copper ores. Only a few miles outside this town of Falun was one of the biggest, perhaps the biggest, nickel mine in Sweden. This nickel mine was at Slattberg and the nickel works were at Sagmyra, near by. Shortly after the Franco-Prussian war these mines were bought by some German interests which probably controlled the nickel refining business of the world at that time. That old mine was in the '70's producing copper-nickel matte by smelting, like all the other Swedish mines in those days; there were four or five of them, all smelting a very low-grade matte and treating that low-grade matte with sulphuric acid so as to obtain sulphate of iron as a by-product. The sulphuretted hydrogen was taken into chambers and made into sulphuric acid. The residue, containing sulphide of copper and nickel, was sent to Germany as such. In the middle of the '80's when I started as apprentice at the copper works in Falun, Mr. Hendrik Munktell, also owner of the world-famous Gryckbo paper mills where the Swedish filtering paper is made, was the general manager of these old copper works which were using the Henderson process for chloridising copper ores. Henderson was manager of the Tharsis works in Glasgow in those days—the '60's and '70's. The Germans had stopped working the nickel ores at Sagmyra when the New Caledonian ores were found, and the plant had been shut down for more than ten years, when it occurred to Mr. Munktell that the Sagmyra ores might be treated by chloridising roasting, and my first employment in the nickel industry was to make a series of experiments beginning on a small laboratory scale but afterwards enlarged, with chloridising roasting of copper-nickel ore, extracting the copper and nickel with water and acid, and afterwards refining that solution in one way or another. It would take me too long to go through all that. In those experiments we met with so much success that Mr. Munktell, who was a rich man, got some other people with him and established works with this process at Hommelvik, in Norway, where they used nickel ores from different mines in Norway, which were considerably richer than the Swedish ores. We started building in 1887, and were able to produce nickel in 1889, 1890 and 1891. I was the superintendent of these works, and the processes had all been worked out by me. But the production at the best amounted only to 50 tons a year. In those days we were being paid 80 cents a pound for the nickel. Practically all the nickel was sold to a gentleman whom you will probably see when you get to Sheffield to-morrow, Mr. Doncaster.

Q. I know him well—Samuel Doncaster? A. Yes, he was part owner in those works, and he visited them and he knows me very well. We were getting through our troubles in that plant and beginning to make some money, although in the meantime nickel had gone down to about 60 cents a pound, when one day in the autumn of 1891 we read an article in the "Engineering and Mining Journal" to the effect that Col. Thompson, the president of the Orford Company, had made a contract with the United States government to supply them with a million dollars' worth of nickel at the rate of 30 cents a pound, and this was at a time when we were getting from 60 to 80 cents a pound. I advised my friends to shut down their plant, which they did in the spring of 1892, and I went over to America to see what the Orford Copper Company were doing. When I arrived there, I found that they had been experimenting off and on for several years with the nickel contained in the copper matte which they got from the Canadian Copper Company's little smelter at Copper Cliff. The matte was originally treated as a copper matte and no payments were made for nickel, and the Orford Copper

Company did not save it. However, in 1890-91, they experimented with a process which seemed to promise to be of some use, and it was on the strength of that process that Col. Thompson made this contract. In this process the Bessemerised matte was treated with sulphuric acid so as to dissolve out the nickel as sulphate.

Q. Was that after roasting? A. No.

Working Up the Orford Refining Process

Q. The raw matte? A. Yes. The copper sulphide is very hard to dissolve; the nickel sulphide dissolves easily, and by not roasting the matte, it was possible to obtain a nickel sulphate free from copper. The solution so obtained was boiled down to dryness and the crystals roasted, whereby nickel oxide was produced, and this was delivered to the United States government on account of the contract. It was soon found, however, that they were not able to get anything like all the nickel dissolved in that way. The process was very costly, and Col. Thompson found that he had made a bad bargain. If they could not invent a new process in a hurry to make nickel at 30 cents a pound when the market price was 60 cents a pound, they would not be able to fulfil their contract. So they started looking up all the old patents, papers and metallurgical books, and particularly the patent descriptions of the United States Patent Office. They found one, which for some reason or other took their eye, invented by an old brass smelter in Torrington, Connecticut. I do not know whether you are aware of it, but there is some copper-nickel ore there. This process consisted of smelting copper-nickel matte with soda salts, whereby copper sulphide and sodium sulphide formed the top, and nickel sulphide formed the bottom. I might state here that this separation of nickel from copper was known in Europe and in use many years before the Orford Copper Co. took it up. The patents granted to Bartlett, John L. Thompson and R. M. Thompson are for production of a commercially pure nickel by repeated smeltings with soda salts, whereas the old processes only used the reaction for removing the bulk of the copper. When I arrived in New York in the spring of 1892 the Orford Copper Co. had just got that process perfected in such a way that they were smelting their matte with nitrecake four or five times and obtaining a nickel sulphide containing over 70 per cent. nickel, 1 per cent. arsenic, some antimony, at least 1 per cent. iron and 1 per cent. copper as the principal impurities.

Q. Was that from the Sudbury ore? A. That was from the Sudbury ore. They had a contract for refining all the material that the Canadian Copper Company could give them. The armour plate makers soon found out that to make a good armour plate they had to have better nickel, consequently the United States government required the nickel oxide to be free from arsenic, and the copper content was not allowed to be above 0.25 per cent. I was able to show them how to get rid of the arsenic by a small change in their ordinary practice, and as a reward for that I was engaged in the company's employ to build a plant to make metallic nickel. I built that plant in the spring of 1893 at a place entirely separate and about two miles distant from the main works of the Orford Copper Company. In the meantime I had been allowed to study the metallurgical practice of the Orford Copper Company, and on account of the experience I had obtained in Norway, I saw how I could greatly improve upon their metallurgy. However, nothing was done until 1895, when the specifications for nickel became stricter, and it became impossible to sell nickel oxide for armour plate containing more than 0.15 per cent copper, which quality it was impossible to obtain by the top and bottom smelting, at least in an economical way. They were then repeating their smeltings with nitrecake from 7 to 9 times. In my work with the Henderson process at the plant in Norway, I had found how differently the copper and the nickel behaved when they were being chloridised in a roasting furnace, and it occurred to me that it would be much easier to extract the last trace of the copper by chloridising roasting and leaching instead of by this top and bottom smelting.

As I said, it was in 1895 that I was allowed to demonstrate and introduce this process at the Orford Copper works because they had been unable to find anything else that would save the situation. I could just as well have done it in 1892, but they would not let me, as there was a great deal of jealousy about it. When my scheme proved successful, I was given charge of the nickel department. Later on, in 1897, when I was given complete charge of the whole nickel industry of the Orford Copper Company, I was able to carry out my system in a more finished way, so that it became what it is now, the Orford process, which consists in top and bottom smelting repeated two or three times, leaching with water of the pulverized bottoms, followed by leaching with weak acid to remove sulphide of iron and incidentally also cobalt, and finally two treatments by chloridising roasting and leaching. These two treatments are so carried out that you chloridise the sulphide and leach it, and the resulting nickel oxide is mixed with nitrecake and salt, then roasted and leached, whereby the copper contents of the nickel oxide are reduced to only a few hundredths of 1 per cent.

When I had introduced all these improvements I was promised by Col. Thompson to be taken in as a partner, but unfortunately at the time he was selling out and rearranging his affairs I was taken ill with malarial fever, so that I was practically useless for two or three years. When I came back to health again I found that the International Nickel Company was

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formed, and that I had been allocated a very insignificant proportion of what I had been promised. This to a great extent was simply due to the fact that I had been ill and that nobody had thought I was going to recover. If I had been strong and healthy, I suppose I would have been able to hold my own—a little better than I did, at least. You can understand how I had had to work during the years I had charge of the Orford works. I was practically the only scientifically educated engineer with the Orford Copper Company and the Canadian Copper Company, and I had had single-handed to change the process and at the same time increase the production from 200,000 or 300,000 pounds of nickel to 1,000,000 pounds a month. This I did inside of three years, 1897-1900, without at any time stopping the works, by simply adding to and changing them around in the best way I could, and in addition without any particular appropriation of money to do it with.

Q. All the time I suppose you were adapting the old works to your requirements? A. Yes, that was it. Well, when I had the Orford process as well developed as I thought I could get it, in the year 1900 it seemed to me that it was not without its faults; the quality of the nickel was not as good as that of New Caledonia; the number of processes that the material had to go through made it utterly uneconomical, not to say impossible, to work on a small scale. The only reason that the process is economical is that it is carried out on so large a scale by the International Nickel Company. It is, however, a tremendous improvement upon the nickel processes which existed before 1892, and upon all others that had been invented in the meantime.

Invention of Electrolytic Method

I concluded in about the year 1900, or perhaps 1899, that the only correct way to handle the problem of separating nickel from copper was to make the matte into an anode, electrolyse that anode and obtain the nickel at the cathode directly; and I set out to solve that problem. I did solve it in a laboratory way at the time, and informed Col. Thompson of the fact; but inasmuch as he was not the owner of the mines and smelters, and had simply a short time contract for refining, he did not consider that he could afford to change the whole of his plant. Consequently nothing was done. But in 1904, while I was in the employ of the International Nickel Company as their metallurgical engineer, I informed Mr. Monell of the existence of this process, and he agreed with me to give it a trial and promised that I would get a certain payment in case it was accepted. A plant was built for electrolytic refining in the summer of 1904 at the Orford works, but just as it was about to be started, or just as it was started, and I had shown my ability to produce nickel in that way, I was ordered to patent the process in the name of the Orford Copper Company and hand the patents over to them without any payment. This was entirely contrary to the original agreement, and I had no other course than to leave the company's employ. I was shortly thereafter asked to build a plant for the Lake Superior Corporation which owned some nickel mines in the Sudbury district, but—I do not know what to say—through the peculiar feelings of some of the directors, the board of directors could never be made to agree to build a plant, and after having spent almost a year in negotiations I had to give it up. I then got together some very rich people in New York more or less affiliated with what is known as the "Standard Oil crowd," and took an option on some mines and began to prepare for the building of a plant; but just then some of the directors in the new company found that they had friends who were interested in the nickel business with whom they would not care to compete, and therefore I was told that they would not go into it. This adventure had lost me another year.

Tried at Fredericktown; Installed at Kristianssands

After that I got an offer to go down to Missouri and build a plant for treating the complex ores of the North America Lead Company at Fredericktown. I never thought that their ore bodies amounted to very much, neither could I see that their chances of ever becoming a large factor in the nickel business were very good, but I thought that it would be a way of introducing my process for separating copper and nickel on a large scale, and I therefore accepted the proposition. To make it go through I had to put up a great deal of money, much more than I could afford, out of my own pocket. I went down there, and in the years 1906 to 1909 I worked out and started the process which, as far as the metallurgy went, was successful. Not only was I able to separate the copper and nickel, but also to separate out in a novel way the large quantity of cobalt that was present in those ores.

Q. Do you happen to remember the assay of that ore? It is only a matter of general interest, but the relative amount of nickel and copper would be important? A. It was a lead ore in limestone which, together with the galena contained a nickel-cobalt mineral called linnaeite, and also some chalcopyrite. The values in copper, nickel and cobalt varied very much, but in concentrating the material in the ordinary wet lead concentrating-mill a middling was obtained containing, outside of fairly large quantities of lead, about 4 per cent. copper, 2 per cent. nickel and 1 per cent. cobalt. This was the raw material for my process. The process worked well, and we were making money when I was suddenly notified that the board of directors would not carry on the work any longer, and they shut the place down without

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any good reason. In the meantime I had been approached by my old friends in Norway who were interested in using my process in that country. They sent their engineers to Fredericktown to inspect the copper-nickel part of the plant, and upon receiving a favourable report from these engineers the Norwegians made a contract with me for building the plant at Kristianssands in Norway. To define the state of perfection of the process at that time, I will say that the original plant at the Orford works had been designed for a material containing two parts of nickel to one part of copper, but it was used for so short a time that I was unable to learn anything from that installation. The new installation in Fredericktown had necessarily to be made in a different way—only the main principle was the same—on account of there being so much more copper and so much less nickel, and particularly on account of the presence of considerable quantities of lead and cobalt. When it again came to handling the material in Norway there were other considerations, such as the high price of coal and cheap electricity, which made it necessary to again change the process. But although the first plant put in in Norway could in consequence be said to be an experiment, it worked very satisfactorily from the beginning. It had only been operated for half a year when it was concluded to double its capacity. It was started in 1910; the capacity was doubled in 1911 and 1912, and again increased in 1914, so that the capacity at the present time is about 1,800 tons of nickel per year.

Q. And copper? A. 1,200 tons.

Q. And precious metals—do you take much notice of those? A. Oh, yes.

Q. Can you tell us anything about them? A. Well, the ores vary very much, just like they do in Canada.

Q. I suppose the palladium would be more than the platinum, as it is in the Canadian ores? A. Yes.

Refining Operations in Norway

Q. What is the cost of erection of the plant? A. The actual cost of the plant, as it now stands, with a capacity for 1,800 tons, was about $250,000.

Q. That 1,800 tons is nickel? A. Yes. We are not using it to that capacity now, on account of our inability to obtain raw material during the war. We are only operating the plant to half its capacity.

Q. Is that entirely on Norwegian ore at the present time? A. Entirely on Norwegian ore.

Q. From the two mines? A. Yes.

DR. MILLER: By raw material you mean the ore? A. Yes.

CHAIRMAN: And matte? A. Yes, and scrap. We bought a good deal of German silver, scrap and turnings, and things of that kind. The refining plant, where we used bessemerised matte, is built very cheaply, perhaps a little too cheaply; it is a wooden structure. It is doing the work, however, and the actual cost of refining is in ordinary times, not figuring on war prices, between $100 and $110 per ton of nickel.

Q. Does that include roasting of the matte and the making of anodes and everything? A. Yes.

DR. MILLER: That is the total cost? A. From the Bessemerised matte to nickel cathodes, electrolytic copper ingots and precious metal slimes. There is no cost on the copper, all the cost is figured on the nickel.

Q. What is the ton? A. It is the metric ton.

MR. YOUNG: 2,204 lbs.? A. Yes. We have demonstrated these cost figures to the satisfaction of Mr. J. E. McAllister, of Toronto, Mr. W. A. Carlyle, of London, Mr. W. R. Deacon, of New York, and several well known American engineers.

DR. MILLER: If you were working on a larger scale, as you hope to do, in Canada, they would probably be reduced? A. Yes. The material that we are using is 6 to 8 tons of coal per day, a few tons of coke for smelting the anodes, and about 1,800 horse power of electricity for making these 1,800 tons of nickel per year. This power consumption includes blowers, elevators, lighting of plant and so forth.

CHAIRMAN: How would your electric power costs compare with those in Ontario at say $15? A. We are paying at present 45 crowns, which is practically $12—we are practically paying $12 per horsepower year, for high voltage current delivered at the refinery.

MR. GIBSON: What does your coal cost? A. Our coal in ordinary times costs us between 18 and 20 crowns per ton delivered at the refinery. This is about $5 a ton.

Q. And your coke? A. Coke costs $7 a ton.

Q. Are these long tons? A. Yes; and we have about 100 men employed in three 8-hour shifts, paying them an average of 13 cents per hour.

CHAIRMAN: Could we say that throughout the information you give us you are always speaking of the metric ton? A. Yes. Of course the coal and coke which comes from England is different.

Q. It really would not make much difference? A. No.

MR. YOUNG: It is 36 pounds difference per ton, I think.

CHAIRMAN: We have descriptions of your process in Dr. Coleman's report. Could you give us one which we could publish as your own description, giving what details you

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thought best? A. The process is thoroughly described in its main features in the patents which have been granted to me in the United States and Canada in the years about 1905 and 1914-16.

CHAIRMAN: There were two taken out very recently, were there not? A. There were four taken out on the main improvements which we have introduced during our work in Norway.

Method Suitable for Ontario Ores and Conditions

DR. MILLER: Is there any reason whatever why this process of yours, which is in successful operation in Norway, cannot be put into practical operation in the Province of Ontario? A. There is absolutely no reason. The ores which we are working, Norwegian ores, give us on an average 1.0 per cent. nickel.

CHAIRMAN: Does that mean recovery? A. Yes, yield. None of the mines is worked at a greater rate than 100 tons a day. The process consumes absolutely no chemicals whatever.

Q. Of course that would be a great advantage to us? A. I mean, outside of lead for linings of tanks, and firebricks and ordinary repairs of furnaces.

Q. And as regards waste liquors and that sort of thing? A. There is none. The solutions are automatically regenerated, so that the main solution with which we started in Norway five years ago is the same one to-day. It has never deteriorated at all. Of course we have had to make some more, and we have it in our power automatically in the process to obtain an increased bulk of such solution, so that when we have increased our plant we have automatically increased the bulk of the solution.

MR. YOUNG: And there is nothing noxious or harmful or offensive in the process? A. No. The same workmen who were with us when we started are still with us, and they are in a good, healthy condition.

Q. And there is nothing to hurt outsiders? There is no discharge? A. No. We are in a fine garden district, and we have had to put up a 150-foot high chimney for the sake of getting rid of the sulphurous acid which results from roasting the matte.

CHAIRMAN: When you are preparing your anodes, you roast to a certain point, I suppose? A. Yes.

Q. But there is no trouble with a reasonably high chimney? A. No.

DR. MILLER: Could not the making of the anodes be done at the smelter and the anodes shipped to your works? A Yes, or the roasting can be done at the smelter, and anode melting done at the refinery.

Q. No sulphur would be given off? A. No, at least only an insignificant amount.

MR. GIBSON: Do you roast your ores in the open air in heaps? A. No, we do not roast them at all All the sulphur which comes off comes off in the bessemer converters.

MR. YOUNG: You were saying that you were in a garden district? A. Yes.

Q. A populous district? A. Yes.

MR. GIBSON: Do you have any appreciable losses as between the contents of the ore and the recovery? A. Our slags contain on an average 0.15 per cent. nickel and 0.1 per cent. of copper.

Q. You said you had 1.0 per cent of nickel recovery, but you did not mention the copper recovery. A. That is about 0.7 per cent.

Q. With the richer ores at Sudbury the percentage loss would be reduced? A. Yes.

CHAIRMAN: Your total losses per ton of ore would be practically the same as in Norway, and therefore proportionately less? A. Yes.

MR. YOUNG: How does the cost of labour compare in the two countries? A. It is cheaper in Norway. We are paying our workmen 13 cents an hour on an average, working 8 hour shifts. You have to pay about double, I suppose?

Q. Easily. A. A plant making two or three times as much as we are making in Norway, would only need 50 per cent. more labour, so that when we are working on a larger scale that will even itself out.

DR. MILLER: Your mining costs would be lower? A. Yes, very considerably lower. Our mining costs are about $2 a ton of ore, whereas we do not expect it will cost anything like that, not much more than half of it, in Canada. Our smelting costs are about $2 a ton of ore, and that can also be decreased very considerably when working on a larger scale.

MR. GIBSON: Why do you expect the cost of mining in Canada to be less than in Norway? A. On account of the larger ore bodies.

Q. Notwithstanding the fact that our labour is much dearer? A. Yes.

DR MILLER: You said you were mining not more than 100 tons a day from the larger mine? A. Yes.

MR. YOUNG: In taking your costs from the books do you distribute the overhead charges? A. Yes.

Q. Over the whole? A. We have a cost-sheet which will be laid before you, which shows the whole costs divided up into some 20 or 30 heads, beginning with freight to the plant, then the weighing in, the crushing and sampling the roasting and anode smelting, electrolysis, copper refining, steam generation, precious metals, recovery; and such charges as superintend-

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ence, office keeping, taxes, insurance, selling expenses, and so forth, each item by itself figured out per ton of nickel.

CHAIRMAN: That answers quite a number of little points I had intended to ask you.

MR. YOUNG: Does the Government audit check your costs? A. Yes.

Q. As well as your general expenses? A. Yes.

MR. GIBSON: Does your company publish a printed report for the information of shareholders? A. No, we do not. We do not publish anything. We have our annual meeting at which we read a report behind closed doors to stockholders only, with instructions to keep it to themselves; and the printed report which is given out is not supposed to be any better than the one which the International Nickel Company is publishing.

Details of Process

CHAIRMAN: Could you give us any particulars—we have got them from the other companies and it would be convenient if we could get them from all—as to the analysis of the ore, of the matte, and of the metallic nickel and metallic copper—anything that you would probably like to be published? It would make the whole thing on all-fours. A. The ores from the different mines vary very much. Taking the whole smelting mixture, I would say that the ore analyses 1.3 per cent. to 1.4 per cent. of nickel and about 0.9 per cent. of copper; it contains in one smelter 20 per cent. of sulphur, 35 per cent. of iron, and 35 per cent. of silica.

Q. Would that mean real silica—or what we call silicious matter? A. Real silica, and the rest, lime, alumina and magnesia. The blast furnace slag which we throw away contains on an average 0.15 per cent. nickel and 0.10 per cent. copper; and the Bessemer matte which we produce contains about 50 per cent. of nickel and 30 per cent. of copper. The main thing about the bessemerised matte is that we bessemerise it to contain about 0.5 per cent. of iron.

Q. That is almost identical with the Canadian practice, is it not? A. Yes.

Q. And the reason for that, I presume, is to avoid the excessive loss of nickel which occurs if you carry it beyond that stage. Is that so? A. Well, you cannot carry it beyond that stage.

Q. You cannot get rid of any more sulphur? A. You cannot get rid of any more; that is the utmost limit. It is very hard to get that, because it freezes. The bessemerising cannot be carried any further, and there is no use in carrying it any further. Of course it might be a nice thing if you could get it down to 0.1 per cent. or 0.2 per cent. of iron, but it does not matter.

Q. I was thinking more of getting rid of the sulphur for the manufacture of anodes. A. You do not want that for other reasons. There are ways and means of getting rid of that sulphur easily enough. We really do not want to go any further. We do not want to get rid of that sulphur.

Q. But in making your anodes, could you use those containing as much as 20 per cent. of sulphur? A. Yes, but they would be so brittle that they would not last so long. There is no chemical reason why you could not, but there are practical reasons such as brittleness of the anodes, and bulkiness, and so forth.

Q. Did you give us the assay of the nickel? A. I was going to give you the assay of the nickel.

Q. We have got so far as the matte now? A. Yes, the nickel can be produced without any chemical difficulty up to 99.9 per cent. pure. But for practical and commercial reasons, there is no use in going to such a high grade, and therefore we are only producing a quality that is competing favourably in the market. We have never since we started had any complaint against the quality of the product.

MR. YOUNG: If the market called for pure nickel, you could meet the demand with your process? A. Yes.

CHAIRMAN: Could you guarantee it free from copper? A. We can make it down to 0.01 per cent. or 0.02 per cent. of copper, but we are not making it down to more than about 0.1 per cent. because the market does not call for anything purer. We could make it practically free from iron, but we are leaving about 0.50 per cent. of iron in it.

Q. Any cobalt, I presume, goes in and is called nickel? A. Yes, any cobalt that stays in the bessemerised matte goes in with the nickel, but in bessemerising, when you get rid of the iron you lose the bulk of the cobalt also The nickel which we produce is guaranteed to contain less than 1 per cent. of cobalt, but it very rarely contains more than 0.50 per cent.

Marketing Nickel in Germany

MR. GIBSON: Where is your market for the nickel? A. We are selling our total output on a long-time contract to Germany. It was sold by the German company before the war in England, Italy and Russia, but is now going exclusively to Germany and Austria.

Q. Has nickel materially increased in price since the outbreak of war? A. Yes, but we have not had any very particular benefit from it.

Q. By reason of your long-time contract? A. Yes.

MR. YOUNG: That is hard luck? A. Yes.

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Q. Did I hear some gentleman at one time say that there was an objection to the electrolytic process in operations of any magnitude—that as you get handling enormous quantities of ore the electrolytic process is not so adaptable as with a smaller quantity? A. I can tell you something about that. I heard it to-day from Mr. Dunn. A short time ago some large financial interests in New York were asked whether they would help to finance the British America Nickel Corporation, and without any further thinking over if it would be advisable, they went right to the International Nickel Company for information and were told that they knew my process very well, which they do not. They were also told that although they admitted the process was worked on a very small scale in Norway, it was so intricate chemically and had so many operations that it was impossible to work it on a large scale. I would say that it was just the other way round. The Orford process is many times as intricate as the present electrolytic process. Half a dozen world-renowned engineers who have seen the plant at Kristianssands have never for one minute doubted that it could be carried out on any scale whatsoever.

MR. YOUNG: It is only fair to say that those remarks, as I understood them, were not directed to your process, but were made in the course of discussing the electrolytic processes in general. A. Yes.

MR. GIBSON: Do you know of any climatic difficulty in working your process in Ontario? A. No.

Q. Would it be workable in the Sudbury district? A. Yes.

Q. There would not be any difficulty in the way of extremes of cold and so on? A. No. I have installed an equally intricate electrolytic process in the north, where they sometimes have 50° below zero.

How Copper Recovered, also Precious Metals

CHAIRMAN: You have not given us the composition of the copper. Do you melt that down, or sell it as precipitate? A. The copper is recovered as cement copper, together with the precious metals, and the cement copper is melted down to anodes which are electrolytically refined.

Q. By you? A. Yes, by us. It is carried out exactly in the same way as the ordinary electrolytic refining of ordinary copper material, whereby we get the electrolytic quality of copper equal to any on the market.

Q. I suppose you sell the anode mud containing the precious metals? A. Yes.

Q. You do not smelt that? A. No.

Q. That is just the same as the ordinary electrolytic blister copper practice? A. Yes.

Q. Do you make any nickel salts or copper salts? A. No.

Q. No oxide—nothing but the metals? A. No. We can if we want to, but so far we have not. But that again would involve consuming sulphuric acid, which we naturally could produce ourselves.

MR. GIBSON: Do you make any use of the sulphur at any stage of the operation? A. We get automatically in our process enough sulphuric acid in the roasted material to supply us with whatever sulphuric acid the process needs.

Q. Is that a considerable quantity? A. No, it is a very small quantity.

CHAIRMAN: It comes from the oxidation of the sulphur in the anodes? A. Yes.

MR. GIBSON: That is converted into sulphuric acid? A. It is automatically, without doing anything to it, worked into sulphuric acid in the process.

CHAIRMAN: How do you precipitate your copper as precipitate? Is that from the solutions from the electrolytic deposition of the nickel? The mother liquor will contain the copper? A. No. My electrolytic process consists mainly in that you have a large quantity of nickel sulphate solution which is all the time circulating in the plant between the nickel depositing department and the copper depositing department. In the nickel depositing department the anodes are dissolved whereby both copper and nickel go in solution. Only nickel is deposited, and the solution carrying the copper is pumped over into the copper department where cementation on slabs of metal identical with the anodes takes place; the copper is deposited as cement copper, and the nickel dissolved from the slabs, whereby the solution is made free from copper and returned to the nickel department to take up more copper.

Q. You are managing director of your Company, are you not? A. No, I am not; I am consulting engineer and one of the directors.

MR. GIBSON: Have we the name of your company? A. Kristianssands Nikkelraffineringsverk.

CHAIRMAN: We will send a transcript of the shorthand notes to you. A. It might be recorded that the refining does not include any loss whatsoever of copper, nickel and precious metals except such incidental losses as may occur through leakages and things of that kind.

Q. In other words, all the losses which we have been discussing are those in the production of the matte? A. Yes; and so far as we can analyse, all the precious metals are recovered.

MR. GIBSON: If we have not time to visit Norway, would it be possible to get a copy of your costs of which you spoke? A. Yes, for private information; certified by the official reviser (chartered accountant).

[*V. N. Hybinette.*]

Q. Could we have the items in English so that we can understand them? A. Yes. We have made them up in that way before.

DR. MILLER: You have had some experience in handling New Caledonian ores, I think? A. Yes.

Mixing Norwegian and New Caledonian Ores

Q. Could you give us the cost per ton of the New Caledonian ore? A. I can give you some particulars regarding the treatment of New Caledonian ore. The New Caledonian ore is in a metallurgical sense different from the Canadian or Norwegian ore, in that it is practically free from copper. Heretofore the main cost of refining has been in the separating of nickel and copper, and the refiners of New Caledonian ore have therefore taken great pains not to introduce into their furnace charges any material containing copper. The New Caledonian ore is so composed that it requires a great deal of fluxing, and, inasmuch as practically all available iron fluxes contain some copper, the fluxing of the New Caledonian ores has heretofore been done by using limestone, gypsum, fluorspar and the residues from the Leblanc soda process. This, however, has had its effect on the cost of making nickel from New Caledonian ore, inasmuch as it has been impossible to treat the ore unless there were quantities of cheap fluxes to be had. And even at that with the cost of fuel, the large quantities of flux and the nature of the mixture, the fuel consumption in smelting New Caledonian ore has been very large. My electrolytic process for separating nickel from copper is so cheap that the old objection to introducing the copper is no longer good, particularly as the ores generally contain a certain amount of precious metals, which pay part if not all of the refining costs. We have therefore lately started the practice of mixing our Norwegian ores with New Caledonian ore, and it has been very successful. No barren fluxes whatsoever are necessary. The fuel consumption, on account of the presence of iron and sulphur, is very low. The slag we obtain is of such a composition that the nickel content thereof is surprisingly small. The ore from our mines can be mixed with New Caledonian ore without briquetting, which is usually done in the ordinary practice of smelting New Caledonian ore. So far as we have been able to find out, we are able to treat the New Caledonian ore in this way cheaper than by the ordinary present practice.

CHAIRMAN: Could you tell us what the amount of iron is, and the general composition of the New Caledonian matte as sent over—the first stuff is about 45 per cent. of nickel, I believe—and how much iron that contained? A. The New Caledonian matte that now comes on the market is partly produced by electric smelting, whereby the objections which I just mentioned to a great extent fall away. But the trouble is that electric power in New Caledonia can only be had in very limited quantity. There is a ferro-nickel produced called matte; we have had some of it; it varies very much in composition.

Q. Would it contain a great deal of sulphur—say 20 per cent.—or more, or less? A. We have had some that really was a matte, and we have had some that really was a metal. From the little experience we have had from buying material from them, I would say that they have not yet got on to a settled practice of production, but I may be wrong in that.

DR. MILLER: There are one or two questions I should like to ask. I started to ask you what the cost of New Caledonian ore is, laid down in Norway? A. I thought you meant treatment. Well, that varies very much, because the freight charges vary enormously. Under ordinary conditions we can get the 5½ to 6 per cent. ore laid down in Kristianssands for about 11 cents per pound of the nickel contents. That would be about the average price, which I think is about the same price as here in England.

Q. Ordinarily, that ore will run to about how much of nickel? A. 5½ to 6 per cent.—between 5 and 6 per cent.

Q. Have you any idea of the cost of refining it by the methods employed by the French company and its branches? A. No, I do not know, but I can make a good guess. I suppose I should say about 6 cents per pound of nickel.

Q. This would mean the total cost of refined nickel from New Caledonian ore about what? A. Say 17 to 18 cents per pound.

Q. What is the cost of refined nickel by the Mond process? A. It may be as much as 15 cents per pound.

SECTION H

THE CANADIAN COPPER COMPANY

Evidence of Mr. A. D. Miles, President, Canadian Copper Company, Copper Cliff

(Toronto, 22nd December, 1916)

NOTE—At the outset of their work, the Commissioners handed to Mr. Miles a list of inquiries regarding the Canadian Copper Company and its operations, methods, etc, to which full and satisfactory replies in writing were duly received. Naturally, many other points of interest developed during the course of the investigation, and these were taken up with the company, partly by correspondence, and partly by personal interview. In order to complete the data as regards the company, Mr. Miles attended a meeting of the Commission held at Toronto in December, 1916, and gave the testimony printed partly below, and partly also in Sections B and N, dealing respectively with Nickel Ore Reserves and Nickel Refining in Ontario, and Taxation of Mines.

CHAIRMAN: I expect, Mr. Miles, that the bulk of the queries in this memorandum dated October 30th will have to wait until we have a formal meeting with the International? A. Yes, you will hear from them directly on that. I cannot say whether they will or will not be here, but you will hear directly from them.

Q. So the main thing to-day will be the queries in this letter of December 18th. You have given us such full answers to our previous queries, either here or at Sudbury, or in your memoranda, that there is little else to ask.

MR. YOUNG: I want to get a little information from Mr. Miles on some of the topics of special interest to me later on.

DR. MILLER: Have you a copy of the letter, Mr. Miles, addressed to you December 18th last? A. Yes, I have with me the plans and sections you have asked for. The first is the plan showing the size of the Crean Hill ore body. It is marked with the same geological colours we have always used, and with which I think you are familiar?

Q. Yes. A. (Referring to plan.) The black is the ore and the green is the greenstone. That is the ore on the stope plan. Everything between here is ore just as shown. This is the section through the shaft, so that you have the ore body shown both ways.

Q. That covers the first point. A. The next was the cross-section through the shaft It covers that, too. It shows the shape of the orebody. The next is No. 2 mine, which is coloured in the same way. There are one or two points here which, when you are ready, I think I will arrange to have Mr. Nicholls go over with you. Then there are the channel samples. These shown on the plan are the only channel samples that we had that were taken in No. 2 mine. This is the result of the drilling you asked for at Lady Macdonald mine. The area around Lady Macdonald lake, that is, No. 4 mine, No. 5 mine and No. 6 mine, is on the Copper Cliff offset. To the northeast the older greenstone underlies the ore-bearing norite, and to the southwest there is a granite gneiss. The southeastern portion of the area is a layer of norite, not over 400 feet in maximum thickness, which laps over the greenstone. In the northwestern portion the norite may be deeper. There is a large gossan area which looks to a casual observer to have good possibilities. The area, upon close examination, proves to consist of irregularly placed, disconnected patches of lean gossan. The ore is low grade. The average grade from all holes was copper 0.9 per cent., nickel 1.3 per cent. There were 17 holes drilled in the area, but this did not accurately outline any regular commercial ore body.

Q. Our idea was to get some knowledge of the structural relations of the sill? A. Yes, but it did not prove the structure of the nickel eruptive.

Q. It is a matter of discussion as to whether or not this sill is a dike-like structure, and we are anxious to get what information we can on the various points around the basin. It does not have at present an important economic bearing, but it may have at some time. You have not included any channel samples from Crean Hill or Creighton? A. We have none from Crean Hill that I know of, and we have no regular ones from Creighton. We have taken channel samples at various places, but we have never regularly channel-sampled the ore bodies. I will look up what we have for you.

Q. If you could let us have two or three of those, it would be of scientific interest, because I don't think there has ever been anything like that shown.

MR. YOUNG: I wanted to get a little additional information in regard to the organization of the company, and I thought you could give me the latest details in that respect. This would be in addition to the mass of material that you have been good enough to supply already in response to our request for information of that sort, but I would like to bring it up to date and in one or two respects to clear up some doubts in my own mind. First, we have the officers of the company. Does that represent the officers at the present time? (Statement of officers shown to Mr. Miles.) A. Yes, there have been no changes since then.

The Company's Holdings

Q. And could you give us the holdings of the company in Ontario; we have the information, but I would be glad to verify it. I refer to the company's mines, and the areas of land owned outside of the mines? A. The Canadian Copper Company owns the following mines, all located in the district of Sudbury:—Copper Cliff, Evans, Stobie, Crean Hill, Vermilion, Creighton, No. 1, No. 2, No. 3, No. 4, No. 5 and No. 6. We are at present operating only Creighton, Crean Hill, Vermilion and No. 2 mines. The company owns, by crown patent and fee simple, 19,615 acres of mineral lands. It owns, in joint ownership with others, 1,083 acres, and the surface rights and license of occupation of 3,880 acres located in the district of Sudbury. It also owns undeveloped lands in the counties of Peterborough and Hastings, 72,840 acres. Additional areas are now being acquired in the township of Graham in the vicinity of our new roast yard, and also a considerable area by The Huronian Co., Limited, above our present power plant in the townships of Hyman, Nairn, Baldwin, Shakespeare, Porter and Dunlop that will be flooded when the Big Eddy dam is built.

Q. The International Nickel Company has no lands or mines in Ontario other than those in the name of the Canadian Copper Company, except possibly the power interests with which I will deal in a moment? A. That is all, they have no mineral lands.

Q. In your answer number two as to the cost of the properties a total is shown of $9,224,001.00. That is made up as to March 31st, 1916, the end of your last fiscal year. Would you care to bring that up to the first of the year for us? A. I think you will find there are no changes. (Mr. Miles looks over statement.) No, there have been no changes.

Q. And the same remark will apply to your number three, taxes that you pay? A. Yes.

Q. We will take that for the fiscal year as it is here, though it really could be brought up to date? A. Yes, I can have that prepared for you.

Q. You might make that for convenience to the end of this year? A. Yes, the first of January.

Q. Then you gave us at Sudbury an explanation of your answer number five, in which the average selling price of $142.57 for matte is mentioned, and you told us that that was based on the agreement which you have since produced between your company and the Orford Company to which I will refer presently? A. Yes.

Q. The other questions are largely metallurgical or technical, and are dealt with either in the answers or in the discussion with the Chairman and Dr. Miller to-day. In the letter of the 18th of December we asked you to let us have anything you could in the way of a short history of the Canadian Copper Company. Have you done anything in that way? A. Yes, I gave you a pamphlet.

Q. By Gray? A. Yes.

Q. Would you care to add to that? A. No, I think that covers it pretty fully.

Q. And what we can get from Barlow and Coleman? A. Yes.

The International and Constituent Companies

Q. Then, there is confusion in the publications with respect to the organization of The International in 1912, and I would like to clear that up with you? A. The old company consolidated in 1912 with the Colonial Nickel Company.

Q. There seems to be confusion as to the constituent companies, but I think you and I can settle that. We have talked over that before? A I have furnished you with a list of the companies.

Q. I am referring now to the memorandum you gave us on the 30th of October; I think you have a copy before you. You speak of The American Nickel Works. Is that the Wharton company? A. That is the Wharton company.

Q. Is that the correct title, or was it the American Nickel Corporation? A. It was called The American Nickel Works.

Q. The assets of that company were acquired by The International outright, and it has since been liquidated, hasn't it? A. No, the assets of The American Nickel Works were acquired by The Orford Copper Company in 1905.

Q. And The Orford Copper Company has had the same experience? A. The Orford Copper Company was merged with the consolidated corporation in 1912.

Q. Now, you are sure about the Orford? A. Oh, yes, absolutely.

Q. The Orford Copper Company, the Vermilion Mining Company and the Anglo-American Iron Company have all been liquidated under your American laws in order to provide for the consolidated corporation? A. No, the Anglo-American Iron Company and the Vermilion Mining Company were both taken over by the Canadian Copper Company in 1911. The consolidated corporation owns the Canadian Copper Company.

Q. And the Nickel Corporation, Limited? A. The Nickel Corporation, Limited, is still in existence, but there are other shareholders besides the International Nickel Company.

Q. That is the Whitaker Wright Company, and it is still in existence? A. Yes, still in existence.

[*A. D. Miles*]

Q. The Société Minière Caledonienne is still in existence also? A. Yes, it is still in existence.

Q. The Vermilion Mining Company, is that the same as the Vermilion Gold Mining Company whose property was acquired by The Canadian Copper Company in 1911? A. That is the one, I imagine, although I have never known it by that name.

Q. Then the Huronian Company has been incorporated since; is that its correct name? A. The correct title is The Huronian Company, Limited. It was incorporated in 1902, by Colonel Thompson, Major Leckie and Robert McKay. It was bought from them by the old company.

Q. And is that an Ontario company? A. That is an Ontario company.

Q. So that we can get our information in the Buildings here? A. Yes.

Q. And that is the water power company that owns your water power plant and works at High Falls? A. Yes.

CHAIRMAN: And that also deals with the distribution of your product from Bayonne, doesn't it? A. It did, yes. Formerly The Huronian Company, Limited, under contract with The International Nickel Co., handled all European contracts for the sale of nickel. This subsidiary company was used in order to keep the foreign business separate. When war came on, contracts on the continent were cancelled, necessitating a change of handling, and the International Nickel Company now handles everything direct.

MR. YOUNG: Yes, and there is no question about that from the information we received in England, because the International is not mentioned at all as one of the companies supplying material to the Imperial Government.

Q. And your railroads are operated under The Huronian Company, Limited? A. Only partially. The railroad from Turbine to High Falls and from Crean Hill to Victoria Mines, a total of 6½ miles, is operated under the Huronian charter. No. 3 Mine railroad and all of the yard tracks, a total of about 13½ miles, are operated by the Canadian Copper Company.

Q. Then, can you give me any information about the Colonial Nickel Company of New Jersey, which was consolidated with the original International in 1912? A. Colonial Nickel Company was incorporated in 1912, and was taken over by the consolidated corporation the same year.

Q. It is not likely I would be wrong, if I said that it was a company created by the International to carry out the proposed consolidation? A. I think that covers it.

Q. In 1912 there was a merger of the Colonial and the International Nickel Company, and your officials sometimes refer to The International as "The International Nickel Company, New Jersey." New Jersey is no part of its corporate name? A. No.

Q. And the only change there is in the name was the addition of "The"? A. Yes.

Q. There was a considerable increase in the stock at that time? A. Yes, I don't remember the percentage. However, I think you will get that from the financial statements.

The New Refinery at Port Colborne

Q. Then in 1916 a new company, The International Nickel Company of Canada, Limited, was incorporated. Is that an Ontario company, or a Dominion? A. That I cannot say, but you can get this information from Mr. Britton Osler; the company was formed to do the refining in Canada.

Q. Can you give us any information about the progress of that plant? A. I haven't seen the plant, but I have seen the progress report. The entire plant is being built under contract. The contract was given to the Foundation Company, and from the results to date, I would say that it would be operating probably between the first of the coming October and the first of November.

Q. It is situated at Port Colborne? A. Yes.

Q. And what is its capacity in the way of output, do you know? A. That I cannot say.

Q. Can you give us a general idea of the character of the plant? A. I haven't seen the plant. There is absolutely no connection between the two companies.

MR. GIBSON: You mean The Canadian Copper Company and the new refining company? A. Yes, they are under separate management.

Q. They are proposing to use the same process as they do at the Orford works? A. They will use the same process, and it will be managed by Orford afterwards.

MR. YOUNG: Well, of course, the Orford Company as such does not exist? A. I mean the Orford works of The International Nickel Company.

Q. Do you know anything about any modifications to the system that they had in mind? A. I don't think there are any.

Q. What about the waste discharges, the effluents? A. They have devised, I understand, some means of evaporating them.

CHAIRMAN: Of course that is quite a big problem when you go into a new district, you do not know what is going to happen? A. I am not sufficiently familiar with it to give you

[*A. D. Miles*]

very much information. I believe they are going to utilize the waste heat from their furnaces for evaporating.

Q. Is that supposed to take care of all the discharges such as those now going into the Atlantic? A. Yes.

Q. They told me in a letter of December 15th, last year, the discharge amounted to 155,000,000 gallons of liquor, so they have got a good deal to handle? A. Yes, but there is so much waste heat generated in a plant of that sort that it might as well be used for just such purposes.

MR. YOUNG: Some of our experts are telling us that there will be such an improvement in the operating over here, with the increased plant and modern system, that there will be a material reduction in the cost of refining. Can you say anything as to that? A. No, I cannot say, but the old plant is congested and additions have been made where there wasn't really room for them. This plant has been laid out, bearing all of that in mind, in such a way that the mechanical handling will be very much simplified, and will naturally effect some saving in cost.

Q. Do you know anything definitely with regard to the extent of the holdings in New Caledonia? A. I know nothing of that at all.

Q. I think Mr. Holloway got a copy of your stock subscription system? Is that available for Canadian employees here? A. Oh, yes.

Q. How are they taking it up in Canada? A. It has been taken up very well. When we first introduced it, the foreigners hesitated. We introduced it primarily because there was no incentive for an employee to save his money. We own the houses, so he cannot invest his savings in a home. As a result, he did not accumulate anything. We introduced this system of stock distribution to the employees, basing it on earning power and length of service, and arranging it in such a way that he could invest practically all that it is possible to save, in the stock of the company. The stock is issued to employees below market price at the time it is issued, and they are allowed to pay for it on the instalment plan. We charge them 5 per cent. for the use of the money, and return it if they want to cancel their subscription at any time. I will furnish you with this year's pamphlet descriptive of the whole scheme.

Q. The International issues the usual quarterly returns for the purpose of the stock exchange, and those of course are correct? A. Those are correct and available to anyone. They are issued, however, to shareholders, not to the stock exchange.

Q. Do you recall the stock dividends that have been issued by the company? A. No, I do not.

Q. I know there is a 10 per cent. one, and I think there was a 25 per cent. one at one time? A. I cannot say as to that. The 10 per cent. I remember, that was quite recent.

Q. And the shares have been reduced from $100 par value? A. Yes, to $25.

Contract with International Company

Q. There are one or two other matters I do not understand here, and I am going to ask you to enlighten me. You are now operating your company, as far as the International is concerned, under this agreement of the 31st of March, 1909, of which you gave us a copy? Is this the latest? A. That is the latest. Prior to that time, there were minority shareholders in the Canadian Copper Company, and a complete set of books had to be carried and a report issued to these minority shareholders. Since that stock was acquired, it has not been necessary, except for the purposes of bookkeeping, so the contract has never been renewed, but has been in force ever since.

Q. Were there annual contracts before that, each of the same nature? A. I am not sure whether they were annual, they may have been for two or three years, but they were renewed at set times.

Q. Was there any variation from year to year in the price, 7c. for copper contents, and 10c. for nickel contents? A. Yes, it was varied once that I remember, and possibly oftener.

CHAIRMAN: I was under the impression that there had been no variation in that agreement? A. Oh, yes, from 1902 to 1909 there were changes.

MR. YOUNG: And there must have been a similar agreement before 1902, when the Canadian Copper Company and the Orford Company were at arm's length? A. When they were two separate companies, yes, but I don't know that they are available. That was before we had anything to do with the companies. The mine was owned by one group of men, and the refinery by another.

Q. Yes, but the Canadian Copper Company at that time had everything to do with it? A. Yes.

Q. So that if you could get that, it might be helpful as to the agreements between the Canadian Copper Company and the Orford Company prior to 1902? Have you any other inter-company agreements, the Canadian Copper Company with The International subsidiary companies, except this one? A. Yes, with the Huronian Company.

[*A. D. Miles.*]

Q. Do you know whether there are inter-company agreements between other concerns? A. Not that I know of.

Q. You don't know about that? A. No.

Q. Now this balance sheet is interesting, could I trouble you to look it over for me. (The Canadian Copper Company balance sheet for the year ending 31st March, 1916, shown to Mr. Miles.) You might tell us shortly how you make your balance sheet up here. You are operating with The International Nickel Company under the agreement of 1909? A. Yes.

Q. That agreement determines the price you get for your copper and nickel contents? A. Exactly.

Q. Then on that basis you deal with The International as if they were real purchasers? A. Yes.

Q. And this statement is the result, because you have no other purchasers; you don't sell to anyone else? A. No.

Q. And here are your assets,—property, $9,174,000 odd. Now the assets of The International are $44,000,000 odd. What makes up the difference generally? A. The New Caledonian mines, the refinery, the stock of the Canadian Copper Company, the Huronian Company, the Upper Spanish Improvement Company, and all other subsidiary companies.

Q. Well, could these account for the difference? I am not asking in any spirit of hostility; I have a great zeal for facts? A. The value of these properties, plants and stocks account for the difference.

Q. It covers properties owned and operated. Now this statement of yours is presumably as correct as you could make it; that is, to the value of your assets in Ontario? A. Yes. There is no ore included, that is only the property.

MR. GIBSON: Does that not include the mines? A. It includes the mines as property, as real estate.

Q. Does it not take in the value of the mineral deposits? A. No, it does not.

MR. YOUNG: Then the current assets speak for themselves and are correct? A. Yes.

Q. Now the inventories in The International statement for the same year are $4,000,000 and over, and your metals are only $758,000. What does that inventory include? A. The inventory of The International Nickel Company includes supplies, metals in stock and metals in process. The inventory of The Canadian Copper Company includes supplies and metals in process only. Supplies $772,000, metals $758,000, total, $1,530,000.

Q. The Canadian Copper Company would not include matte stock? A. No, it includes only metals in process; the matte is shipped as it accumulates.

Q. That would include all their supplies? A. Yes, the difference of $2,470,000 is accounted for by supplies, finished products, matte in stock and metals in process.

Q. Then on your liability side you have noted The Huronian Company, that is not the capital stock is it? A. No, that is the amount the Canadian Copper Company owes the Huronian Company for power.

Q. That would be your charges for power? A. Yes, we operate the Huronian Company.

Q. Then, what is the liability to The International Nickel Company, of $3,937,000? A. That is the balance, or the difference between the total and $5,800,000 which was a dividend.

Q. And then there is another set of entries here that I would be glad to have explained. Take the item of depreciation, you write off $1,611,182 for your depreciation. What does that cover? It is not mineral exhaustion? A. No, it covers plant depreciation.

Q. Then in the same year The International write off $806,000; that must be for their plant? A. Yes.

Q. Do you know on what basis they are making that up, what percentage? A. Yes, a life of fifteen years.

Q. You might explain very shortly your depreciation basis, because it might help us in other aspects of our enquiry? A. The plant and buildings are depreciated on their estimated life. The life of some machinery is little over one year. Some of the buildings and more permanent equipment have a life of considerably over fifteen years. The average life, however, of all machinery and buildings is estimated at fifteen years.

Q. The depreciation, the Chairman points out, represents about 15 per cent. of your property? A. Yes, more than 15 per cent.

Q. Then the item of mineral exhaustion, $1,236,521, is that an actual statement or an allowance? A. That is an estimate based on the tons of ore treated. It is the amount per ton of ore treated set aside to amortize the original cost of the property. It is an arbitrary figure.

Q. Now, The International Nickel Company wrote down $900,827 for exhaustion of mineral. I don't understand that; where have they got any minerals? A. They own all of the stock of the Canadian Copper Company, and of Société Minière Caledonienne, and part of the Nickel Corporation, Limited. The Canadian Copper Company have accumulated a fund for mineral exhaustion of $1,236,521.90, which is a reserve to March 31st, 1916, while The International Nickel Company reserved during the year ending March 31st, 1916, for mineral exhaustion, $900,827.58.

[*A. D. Miles*]

Q. You might explain this entry of The International Nickel Company in current liabilities, and its entry of payment to that Company, of $5,800,000. A. The funds of the Canadian Copper Company accumulated, and the $5,800,000 was a dividend paid by The Canadian Copper Company to its shareholders.

Q. You won't undertake to give us any information upon these questions that we have submitted to the International? A. No, I think some of them I did cover, one or two; for instance, that list of companies.

Q. I can understand that in your position as President of The Canadian Copper Company, the details of another concern would be hearsay information? A. Absolutely, I might have an idea, but I would not have definite information that would be reliable.

MR. GIBSON: You were speaking of the Wharton Company, and the absorption of it by The International Nickel Company. Did that include the Chicago mine? A. Yes, a one-third interest.

Enlarging Water Power Plant

Q. Then you were speaking the other day about enlarging the water power on the Spanish river. Have you any objection to giving us particulars about that? A. None, whatever. With a view to securing a greater output at our power plant to provide a reserve against accidents to any individual unit, a fifth unit is being installed. This unit will be housed in a brick building with reinforced concrete foundation and sub-structure. The unit will consist of 5,500 K.V.A. Generator, direct-connected to a vertical turbine. All necessary step-up transformers and switching equipment to carry the additional output, will be installed, in an addition to the old power house. The new unit will be controlled from the old power house, and necessary cables and control wires, piping, etc., will be installed in concrete ducts between the two power houses. To secure a suitable foundation it was found necessary to build a new power house approximately 150 feet from the old one, and water is taken into the new unit through a circular steel penstock. Necessary head gates and wing walls have been provided to divert the required amount of water from the present bulk head dam, a small section of which will be taken out as soon as the necessary wing walls and head works are completed. This unit should be in operation the early part of next summer. This additional power is required to handle the enlargements which are being made at both the mine and smelter. We have also outlined the electrification of our railroads, which will probably become necessary.

MR. YOUNG: How are your grades? A. We have no serious grades. Coal has become, as you know, almost prohibitive in price, so that we will need a great deal of power within a very few years. In the meantime, there will be a rock fill dam at the Big Eddy that will act as a reservoir to supply water to our present plant in excess of what we can get from the normal flow of the stream; that is, to impound the water as it falls, and draw it off as we need it during the periods of low water.

DR. MILLER: With regard to these plans, Mr. Miles, that you have given us, if we should want to publish any of them, would there be any objection? A. No objection to publishing all of them if you want to. You will need a great deal of information that is there, and possibly more, to determine the geology of the district, and if there is anything more you need that is not there, I will be glad to furnish it.

Q. Then, in this historical sketch that has been asked for, I suppose in that you will refer to some of the experimental work the company did, just very briefly? A. Yes, I think that would be very interesting.

[*A. D. Miles.*]

SECTION I

THE MOND NICKEL COMPANY, LIMITED

Evidence of the Right Hon. Sir Alfred Mond, Bart, M.P.

(London, England, 30th March, 1916.)

CHAIRMAN: We have already received in the form of memoranda from your London office and from Coniston, a great deal of valuable information, and we should like to know whether we may take these memoranda as final, or whether you would wish to modify or amplify them? A. The memoranda were prepared with very considerable care, and as far as they go I can endorse their contents.

First a Process; Then Mines

Q. We are anxious to learn all you can tell us as to the general position of the nickel industry, and especially regarding the question of smelting in Canada and the cost of the various steps in the treatment, the mining, the smelting to matte, and the recovery of the finished products. A. The history of the connection of our company with the Sudbury field is explained in the memoranda, and I think is well known to you. I might very briefly recall it. The discovery which was made by my late father in conjunction with Dr. Carl Langer, of the treatment of nickel ores with carbon monoxide, was made a great many years ago now, and was first applied, not to Canadian ores at all, but to silicate and arsenical ores. In fact, before the company was formed, the first mines which my father had an interest in were in Germany. His attention was then directed to the Canadian fields, which of course at that time were infinitely less developed than they are to-day; and he succeeded in obtaining a certain amount of matte through the courtesy of Colonel Thompson. He made a series of experiments with experimental plant at Smethwick, near Birmingham, and established the commercial possibilities of the process. The question of raw material then became an urgent one, and in conjunction with Dr. Mohr, my father and my brother, Mr. Robert Mond, visited Canada and made a number of investigations which in time led to our acquisition of the Victoria mine and the Garson mine. Of course the affair was a small one then; it was experimental We had all the usual great difficulties in trying to work out a new industrial process, which were many and serious, and at one time seemed very grave indeed. We pulled through all those, and went on developing the business. We did our utmost to develop that field; in fact I think we may claim that we were the pioneers in the diamond drill and the magnetic survey in Ontario. We introduced methods for the discovery of ores, which have since been copied by other people. I think I might also point out that we employed Dr. A. E. Barlow to make a very thorough investigation of the field at our expense—a geological survey—with the object of really ascertaining as far as possible what further hidden mineral resources there were for the purpose of development. One curious thing is worth noting, and that is that, on the whole, our investigation, as well as the investigation of others, disclosed relatively very little that has not been known in the field almost since the commencement. Practically every mine which is in operation to-day was apparently known many years ago. At the period when we began, and for many years afterwards, the field appeared to be more limited in scope and in size than it has since proved to be. At one time refiners were seriously wondering where the ore was to come from, and that was even the case with the Canadian Copper Company at the time when it was taken over by the present International. The idea of depth is entirely altered. When we started, the common impression among mining engineers and geologists was that about 500 feet was the depth to which you could expect these deposits to go. To-day we are working our Victoria mine at a depth of over 2,000 feet, and there does not appear to be any particular geological reason why the deposits should not continue down to the mineable depth, which nowadays lies somewhere between 4,000 and 5,000 feet. That of course has made a very great difference in the aspect of the field as a mining proposition. Then when we started, the bessemerising of matte had never been tried at all; we were the first people who ever bessemerised. In those days nobody had gone to a further state of concentration than the ordinary blast-furnace matte. We introduced bessemerising, which is now adopted as a general process. That has meant a very much greater degree of concentration of ore at the mines than formerly; it has also meant, naturally, a greater expenditure of capital and labour. That is really how the thing developed. I would like to put in here the fact that we had very great difficulties when we started, in getting the nickel made from Canadian ore accepted by the British government for government purposes. I personally negotiated that matter to a large extent.

MR. YOUNG: What objection was made? A. The objection was that it was not as good as the French nickel. New Caledonia nickel not containing any copper was looked upon as the standard; the British specifications all specified New Caledonian nickel. I think it took us a matter of nearly two years to get armour-plate made with our nickel accepted by the British Admiralty—at our expense. The product of the American company at that time was not so good in quality as it is to-day, and certainly not of such good quality as the French. I may say that we have met with that difficulty in other directions, as, for instance, with people making pure nickel goods. It took a good deal of time and persuasion and even lower prices to get them to accept our nickel against the French nickel which they had used all their lives, and the quality of which they knew. We were enabled to do this because our process produces chemically the purest nickel in the world. That is one of its advantages from the point of view of quality, quite apart from price; in fact some people say that it is too good. That was one of the objections made to me at the Admiralty when I went there.

Locating the Refinery

CHAIRMAN: It was the only one they could make? A. Yes. That objection was seriously made to me; I was seriously told that it was probably too pure. We fought down all those points, and we are now on excellent terms with Government Departments. Our nickel is used by a number of the largest British government contractors, by the War Office and by the India Office. In fact, I think I may say that we have rendered considerable service during the present crisis by putting our nickel concern entirely into the hands of the British government from the beginning to the end. At the present moment, we are controlled works under the Munitions Department—practically a government institution. The question of the location of our refining works was one of considerable study and consideration—the question whether we should locate it here or on the other side, or where we should locate it. There were several very powerful arguments for locating it here. One was that the men who worked the matter out and were directing the enterprise were living in this country. It was a new, delicate process, and wanted continual attention, and naturally one wanted to have it close at hand. Then again, it was easier to obtain the kind of labour used to these operations in the metallurgical centre, Swansea, than it was in Canada, where certainly at that time metallurgy had practically not been introduced. I do not know what the position is now.

Q. It has changed a good deal now. A. Those things have all changed since we began, to some extent. Then there was a third very important consideration, and that is, the first of our bulk raw materials was anthracite, and so we naturally selected a site on an anthracite field where we are within a few miles of the anthracite collieries. The second of our bulk raw materials was sulphuric acid, and we were there in a centre where sulphuric acid is the by-product of a good many smelting operations, and was consequently plentiful and cheap. Thirdly, by our process we produce automatically between three and a half and four tons of copper sulphate to one ton of nickel. This copper sulphate, as you are probably aware, is mainly used in France and the Mediterranean for spraying purposes. It is a very bulky article, and the trade is very seasonal. We therefore require to be near a port with good shipping facilities to the markets, and to be in a position to handle rapidly large quantities. All these facilities were found in South Wales, and that is why we located our works there. The works have grown from a relatively small concern to an increasingly important one. We have just completed another unit which we hope to put into operation when the necessary labour can be obtained. We have considered at various times the question of establishing a refinery in Canada. I must frankly say that if the consumption in the Dominion itself was sufficiently large to support a works, I think there would be a good deal to be said on that subject in spite of the higher cost of production. That the cost of production in Canada would be higher than in England I have not the slightest doubt, on the figures I have had presented to me. Of course production in Ontario would be very much higher, as seems to be established. In fact I think that if a works were at any time established in the Dominion, it would probably have to be on the seaboard, a course which I see the International Nickel Company are proposing to follow.

Electrolytic Experiments ; Precious Metals

Q. Have you gone into the question of electrolytic refining in case you had to enlarge your plant? A. Well, some years ago we did go into the question of electrolytic refining.

Q. Ontario would be perfectly all right for that? A. I know my father had a number of processes investigated. I personally do not know very much about them. My brother had more to do with them than I had; he superintended that work to some extent. I cannot say from my recollection that any of them seemed very satisfactory. There seemed to be considerable technical difficulties. One of the difficulties is that you are dealing with an insoluble anode—I think I am expressing myself correctly. You are not transferring, as in copper refining, a metal from a soluble anode to a cathode by means of a solution.

Q. They use either process—either the insoluble anode, or the nickel anode made from the roasted matte and remelted. You know the Hybinette process is used in Norway? A. I have heard of that, but I have never had an opportunity of investigating it.

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Q. The electrolytic processes all round, copper and zinc and everything, have improved so enormously lately that we are very much interested in the question, especially as we have water-power so cheap in Ontario. A. I know. I would not like to offer any very definite opinion on the subject myself. All I can speak of is our experiments that we made at the time. Other people may have made considerable improvements in working in that direction since, but our experiments did not lead us to the conclusion that a process of that kind would be as remunerative or profitable as the process we were working, which is a very economical one. I do not say it would be impossible: I will not put it as high as that; but we have had some experience in the manufacture of electrolytic zinc, and from the financial point of view the results are disappointing.

MR. YOUNG: You were referring to the experiments you first made? A. Yes. I do not know about the electrolytic process. Perhaps you have investigated it.

CHAIRMAN: The great thing is that you recover the precious metals in that way, but so you do in your process. A. Yes, that is one of the points of our process—a very important point. That is a question which perhaps will be developed in the future. Science has no limits, and everybody is learning every year. All I can say is that I am not aware there is any electrolytic process in existence to-day which has been proved to be a real success on a large scale. All those experienced in electrolytic processes know that they are much easier to operate on a small scale than on a large scale.

MR. YOUNG: You have not been directing your attention especially to the subject? A. No, not lately. We have had enough troubles of our own in trying to improve our process, which to-day is not the thing it was a few years ago.

CHAIRMAN: Mr. Corless gave us many particulars as to the assay of the ore, but we have none as regards the amount of gold, silver, platinum and palladium present, or the amount extracted: have you these figures? A. I do not know that I have. I do not know in what form it would be easy to give them.

Q. The simplest plan as regards the ore would be, not to give it as the amount in the ore itself, because I do not suppose you bother to determine it, but if you could tell us what is in the matte, that would be a definite figure. A. We have endeavoured to determine it in the ore.

Q. It is very difficult. A. Of course the quantities are so minute that I never look at the figures from the ore, because I think they are very misleading.

Q. That is what I thought. A. We have, of course, got figures from the matte. I will make a note of it. I do not know how far they are very reliable figures. I would like to point out this: the quantities of these things are very small and the assay is a very difficult one, and the result is you are liable to get very misleading assays. Practically what we know is how much we get from, say, 4,000 tons of matte; that is the way we reckon, practically. We have endeavoured to ascertain it from ores, and we have made hundreds of analyses, and just because we have made so many we get a little doubtful about their value.

Q. Have you an assay of the mattes from the different mines as regards the precious metals? A. I do not think we have.

Q. It would have been interesting. Of course you know the Vermilion mine? A. Yes. That has always had a reputation, and I daresay possibly quite correctly. I do not think we have, because we do not make matte from each mine; our matte is a mixture from three or four different mines. Unless we specially made matte from each mine we could not ascertain it. We have discussed doing it, but we have never done it.

MR. YOUNG: Perhaps you could give us such information as you have? A. Yes; I will give you such general figures as I can, with pleasure.

CHAIRMAN: And especially the recovery every year of each of the four, because that is the most essential point? A. The quantities?

Q. Yes.

MR. YOUNG: Any details or particulars would be interesting to us in other connections, of course. A. I was going to ask you this—I am sure you will not mind my putting the question—how far are these figures going to be published?

CHAIRMAN: It is very difficult to say. A. I mean, take a point like this: these figures are of intense interest to our competitors.

Q. Of course we do not want to do anything which would interfere in that way. A. If I give you the figures of our recovery every year and they work out the value, it gives them an enormous amount of information about our profits and costs and things which of course we have not been anxious to give them. I could give you figures in confidence, which would not become public property, and they would assist you more.

MR. YOUNG: That is a difficulty we appreciate, but I do not see how we can do it. We might be over-considerate and defeat some of our own objects by limiting it too closely. A. If I give you the figures for every year, you see what it would mean. We have always kept those figures entirely confidential, naturally, because they are important. It is not our business to direct other people's attention to the matter more than we can help, though it is common knowledge, of course. But secondly, our competitors, having our balance-sheets, and forming a shrewd idea as to the quantity of stuff produced, could form a very good idea of our costs.

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If you give them these as well, you give them practically all the confidential information which the directors of the company possess. If these figures were not going any further—if they were not going to be published in any blue book—or anything of that kind, of course it would make some difference as to the form in which I could give them.

CHAIRMAN: We have had that in our minds. A. I take it that you must consider a good deal of information from all parts as confidential?

CHAIRMAN: Yes, we do.

MR. YOUNG: Within the limits of our duty we treat everything as confidential; we do it so far as we can. A. I merely wish to draw your attention to this fact, because I am very anxious to assist as frankly and fully as I can, and to give you as much information as I can, if I know the information will remain with the Commission and will not become printed so that everybody can buy a copy, as is very often the case. In that case I can assist you more, as you will readily understand, than I can if I know it will be published in a document which can be bought by our French or American competitors or anybody else.

CHAIRMAN: The probability is that all we should want in this case would be to say that the average is so much and the amount recovered is so much. A. That would not matter.

Q. I do not think it would be necessary to give it year by year in a report for any individual company. A. I would like to press that point on the Commission, because you are all business people, and you will quite readily understand our responsibility and difficulty. I will try to give the information in the most useful way to you possible. We do not really refine our precious metals; we only get them to a certain point and then sell them to refiners.

Q. As the electrolytic people do? A. Yes. We only have a sort of general assay average. Perhaps I may go on with a few more remarks of a general character on the statement I was making. I was referring to the reasons which led us to establish and continue our refinery in South Wales. I would like to point out in the most frank manner that of course we feel that, having obtained our mines and our government patent free of all charges and taxes and royalties from the Ontario government, free of all restrictions and conditions, and having on the strength of this induced a considerable number of people to spend a large amount of capital both in the development of these mines and in the erection of refining works, we think it is quite an inconceivable proposition that any legislative action could be taken which would practically put out of action the capital which has been put in this country—at any rate put it out of action for such a period as will be necessary to find and develop further mines in order to set it going again.

Timidity of Capital

MR. YOUNG: That has been fully impressed upon us in those several memoranda, and very ably, if I may venture to say so. What sort of legislative action have you in mind? A. Some action prohibiting the export of nickel ore or nickel matte from Ontario. That is the only kind of action. I do not know whether such action is possible on the part of the Province of Ontario; I do not profess to be sufficiently a constitutional lawyer. Differential taxation is obviously impossible, so far as I understand the Dominion constitution. I am familiar with the agitation for a number of years now, and I might remark that the course of it does not facilitate the obtaining of credit in England for developing the Canadian mining industry. On more than one occasion bankers and stockbrokers and others have asked me questions, also shareholders; and a sense of insecurity has been created. I have always assured them that, from my experience of the Dominion government and the Ontario government, I felt quite certain that nothing would be done to damage British interests. Some of the newspaper paragraphs which appeared certainly did create a very serious state of uncertainty. It is not quite pleasant to have your banker sending to you asking whether the credit he is extending is all right or not. Because you know credit is very delicate, and confidence in mining and industrial establishments is very easily shaken. I do not think that that is always quite realized. People who are on the inside know all the facts and the bearings of them, but I do not think they always quite realize that people outside interpret these things, perhaps not in the way intended, but in a way which certainly does not facilitate the finding of the very large sums which are necessary to develop the industry. We have already found very large sums of money, and I look upon this thing as in its infancy—I frankly say so. It will be extended to a very much bigger thing.

CHAIRMAN: I have a note to ask you about the future. A. I will keep that till later, but I wanted to put that in because it is a point which it is my duty to make, not only with regard to our company, but with regard to the general financial relations of England and the Dominions. I am very much in touch with financial circles here and over there, and I know how extraordinarily sensitive financial people are. I do not know whether there are any further questions, but I will be very glad to try to answer any which you like to ask me.

CHAIRMAN: I have a note to ask what you can tell us about the arrangements which you make for marketing, and with other companies which produce nickel. These things are very usual; in fact they generally exist in these big concerns, and we want to know if you can tell us anything. A. I do not think I can, not because of anything I would like to conceal,

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but as regards the general thing I really do not think I am in a position to. At the present time there is no kind of arrangement in existence. This company is entirely marketing its own product, except for some arrangement with the French company of long standing which really relates to an arrangement made with various steel manufacturers.

No German Control of Nickel Industry

Q. In France? A. In this country. Of course it is a very difficult thing to disclose all business arrangements—it is giving away other people's affairs, which I feel a great difficulty in doing. Somebody might say, "You had no right to disclose that information." I might say this—and I think it would be satisfactory from your point of view—there has never been any arrangement in existence which has tied this company or which has hindered this company in its development, its output, or its direction of policy. I think I would say this also, because the question has come up, and I think it is only fair to say it, that there has never been any German control whatsoever of the nickel industry, either Canadian or otherwise. It is a notorious fact that some of the German metal brokers had a connection as selling agents. Their position was that of selling agents.

Q. Had they any arrangement as regards the dividing up of the markets of the world? A. No, there never has been any arrangement for dividing up the markets of the world.

MR. YOUNG: There was a feeling in Canada that there had been some arrangement between the great companies with respect to a partition of the field, a division of the market, as to locality, price, and the like. A. There has never been any division of that kind really, except that the Americans tied their market by means of the very high import duty on refined nickel. There has never been anything of that kind with us. A great deal of our business was done directly, and our business with the British and Dominion governments has always been reserved to our own firm. I have always refused to allow anybody to handle any business either with the British or Dominion governments through any agent; I have always insisted on handling that direct. The other things are simply agency agreements on a commission basis, in which the agents naturally undertake to indemnify us from bad debts and to look after the money for us.

Q. Were they exclusive selling rights? A. They were not exactly exclusive. There were a number of important exceptions, so I should not call them exclusive. They were to a certain extent exclusive. You have probably seen statements in the English and the Canadian press which gave the impression that Merton's, who were associated with the Metallgesellschaft, but are one of the oldest British metal firms, have controlled the industry. I can emphatically deny that statement. That is absolutely untrue. They never had any control over or interest in either the capital, the policy, the finance, or the manufacture of this company. They acted as selling agents on a commission basis for our nickel products, with certain important exceptions, some of which I have enumerated. To make my statement complete, I ought to add that as far as the other products of this company are concerned, namely copper sulphate and nickel salts, as well as any precious metal residues recovered, these have been dealt with by the company's sales department without the intervention either of Messrs. Mertons, the Metallgesellschaft, or of any agents connected with them. I would like to emphasize the fact that in tonnage and value the products which have been handled by our sales department represent the largest part of our output. Messrs. Mertons simply acted as brokers to the company for a small percentage of the company's output of nickel. As a matter of fact in 1913 17 per cent. of the company's total nickel sales were made through the intermediary of our metal brokers, and in 1914 28 per cent. In order once for all to dissipate the idea that this company has in any way been controlled or financed from alien sources, I would like to place on record that the following is the number and percentage of shares held in this company by alien enemies: Of the total issued shares and debenture capital of £2,755,000 which is held by 4,739 share or stockholders, £16,867, or 0.61 per cent., is held by 13 shareholders residing in Germany and Austria (alien enemies). Of the staff and men employed by the company in the United Kingdom, 263 have joined the colours since the outbreak of war, although the company is a controlled establishment, and the employees are exempt from military service under present legislation. The company has made arrangements to keep open the positions of the men who have joined the colours, and also pays them half wages, and those who are tenants of the company's houses do not have to pay any rent whilst on service. As regards employees on the staff, they receive during the time they are on service the difference between their salary and army pay. In connection therewith the company has, since the beginning of the war, spent approximately £21,000 as war expenditure, and in addition has given to Canadian and English charities connected with the war a total of £5,400.

CHAIRMAN: You considered Mertons' the most suitable agents? A. Yes When we came into the nickel industry, it was very difficult to get into a close corporation. We did not know the business, and they had been in it for a great many years. Most metals are sold through metal brokers. So far as the governments are concerned, both the Dominion and the British governments, we always retained the right to sell direct, and all our tenders to

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the War Office, the India Office, and the Dominion of Canada, come direct from this office. There have been various discussions at different times with regard to prices, which is not uncommon.

Ample Ore Reserves Essential

MR. YOUNG: I think we should be very glad to have any information that you feel at liberty to give us, because there is some uneasiness on that subject. It would render a service to the Commission, and perhaps to the industry. A. That is why I want to emphasize the fact that there has never been anything which in any way tended to restrict development of the Canadian industry. As a matter of fact, the figures show that it has developed enormously. A thing which has more largely tended to restrict our development has been the necessity of finding sufficient reserves of ore.

CHAIRMAN: And that you have overcome now? A. That, in the last years, we have overcome. I do not think it is quite appreciated by people who are not mining people, what an amount of reserves you want on output. You must base yourself on some number of years' life of your mines. You spend a large amount of money on smelting and refining works. And that life runs into tonnage. We have always worked on that line of thought, that we were not justified in spending large capital sums on smelters and refineries unless we were certain of large ore reserves.

MR. GIBSON: The position has very much improved in recent years, not only with regard to your company, but other companies? A. Yes, enormously. It has, I believe, improved very much so far as the International is concerned. Before the International opened up Creighton, it is a notorious fact that they were very hard put to it to find ore to keep their smelters running. The development of the Creighton mine, which of course was wonderful, altered the situation for them immensely. The drilling at Frood recently has discovered, I understand, very large bodies of low-grade ore. Another thing which has altered the situation is the fact that we can now deal with very much lower grade ores than mining engineers considered possible when we first entered the field. Take our Garson mine, which has developed into a very fine mine. But the Sudbury mines are so erratic; they are not like most mines; they are very erratic bodies and very difficult to estimate. I remember when we bought our first mine, we took over one of the biggest mining experts in this country and paid him a large fee. He went out for some other financial house, and he practically condemned the mine entirely. I saw his report. He said there was practically no ore there. Well, we are still working the mine now, and it is doing very well.

CHAIRMAN: Are you developing the wet dressing of the very low-grade ore, and oil flotation? A. We have been doing some work recently on the concentration of rocky ore.

Q. That would be a very important thing for the country? A. Undoubtedly one change in that district has been the working of poor, rocky ores. As you know, the smelting of rocky ores consumes an enormous lot of flux. The position has changed entirely; whereas at the present time the ore has too much silica, at the beginning we had the reverse condition; the ore was self-smelting when we started. It became so rocky that we had to add an enormous lot of limestone Of course as the furnace output diminishes, the expenses go up enormously. We had an idea, which was a fairly obvious one, of seeing whether or not some method could be tried by which a certain amount of this rock could be eliminated, and concentration established. I would not like to say anything very definite on the subject, except that we are continuing experiments.

DR. MILLER: I suppose that is not so important now since you have developed the Levack mine? A. No, it is not. I think that is very pure ore. But for bodies like Frood it is very important. Frood is relatively poor and rocky ore.

Testing Concentration Methods

CHAIRMAN: It would be some help to you in connection with the sulphur difficulty, if you get a concentrate and then roast it with the Dwight-Lloyd or some other system; the concentration first would be a considerable advantage? A. I do not know that you would ever want to concentrate all your ore.

Q. Oh, no. A. I think you only want to concentrate the rocky ore. We have had to try out a number of combinations—magnetic separation, oil flotation, wet flotation, and that kind of thing. It is still in the experimental stage; we have no real figures as to costs.

Q. How are you getting on as regards the disputes and claims for sulphur? A. I think the Government have been very kind to us recently and have taken out a lot of townships, which I think will assist very much. I think that matter can be dealt with satisfactorily. I think it is not very serious. The land round Coniston is not very suitable for farming; in fact I think some of the people seem to farm in order to get smoke compensation. If you took a man from here and told him it was farming land, I think he would be very much surprised. It is not good soil; it is very rocky and poor.

CHAIRMAN: Can you give us figures with regard to the relative amounts paid for labour in Canada and in Wales, in other words, for mining and smelting to matte as compared with

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the cost from the matte to refined metal? A. Did we give you those figures in one of the memoranda?

Q. I think you gave us merely the relative number of men? A. We employ many more men over there than we do here, and we pay them considerably higher wages. Refining does not really employ such a large number of men as mining and smelting does. Would you like it in amounts?

Q. Something of that kind. A. I will see whether that can be got.

MR. YOUNG: I think Mr. Corless gave us the scale of wages?

CHAIRMAN: Yes. A. The scale is very much higher there than here.

Q. Both for the eight-hour and the ten-hour. I wanted a general statement as to the percentage: taking it at 100 per cent. altogether, how much per cent. for Canada? A. The percentage of the total wages?

Q. Yes. A. I will try to get that for you. I do not think it will be worth while going through these now.

MR. YOUNG: We want the distribution of wages over the whole operation. A. Yes, I will make a note of it and let you have it.

CHAIRMAN: When I was here after I returned from Canada, was I right in understanding that you would give us a memorandum describing your processes, something which we could publish as being supplied by you to show present day practice, and that you would also give us a memorandum dealing with such queries as may crop up to-day, just as you are doing now?

(*At this stage Mr. Robert Mond entered the room.*)

A. My brother, Mr. Robert Mond, may be able to tell you something more about the electrolytic part of the question. You were asking about a memorandum generally describing the process?

Q. Yes, whatever you can give us that we can publish. Then, also, could you supply us with copies of your annual reports? A. Yes, certainly; we will give you a copy of our balance-sheets from the beginning.

MR. YOUNG: And your annual reports? A. Yes.

Nickel Trade After the War

Q. There was something said about the development of the nickel industry, in which we have a common interest? A. Yes—what is going to happen to the industry after the war? I wish we knew!

Q. We were speaking of the question of trade and the lines of possibilities.

CHAIRMAN: It looks as though they will never be able to go back from the use of nickel. A. Of course I am a bull on nickel myself; it is my business. It is very difficult to say what is going to be the future in marine work. Supposing the big battleship disappears, which is not impossible after this war, that will have an effect on the consumption of nickel.

DR. MILLER: Can you give us any statistics as to the amount of nickel which is used for munitions and battleships and so on for war purposes, as compared with the percentage that is used in the automobile industry and for other industrial purposes? A. In ordinary times, you mean?

Q. Yes? A. I have not the figures, but speaking generally the bulk is not used for war purposes. I would not like to commit myself to a percentage; we do not quite know. Some of our customers use it for mixed purposes. You sell nickel to a nickel steel maker and he sells nickel steel, and then you do not know whether the nickel steel he is selling is used partly perhaps for war purposes and partly for crank-shafts. Take Elswick; we sell nickel to Armstrong's; how much nickel which they buy from us they use for armour-plate and how much they put into motor cars, I do not know. I think the armament part of the nickel trade has become less important a great deal in recent years than it used to be. That is my own view of the situation. And I think as time goes on it will become still less important. We find that a large number of steelmakers are now using nickel who did not use it a few years ago. It is used for a large number of purposes, such as crank-shafts.

Q. And bridges? A. In this country nickel steel for bridges is not used at all, I think.

Q. It is used in the Quebec bridge? A. It has been used to a considerable extent in the States. Of course your bridges are very big-span bridges, and here they are not. We have not got the same kind. There has been considerable difficulty; people here do not quite see the necessity of it.

Present and Future Use of Nickel Steel

(Mr. Robert Mond): Another thing is that nickel steel, being so much tougher than ordinary steel, manufacturers found it difficult to handle with the ordinary machine tools with which engineering works are equipped, and the ordinary methods of using them. Now, with the very extended use of nickel steels, practically everybody working with them, they have had to equip their works accordingly and teach the men how to deal with them; they have had to

[*Sir Alfred Mond; Robert Mond.*]

have their tools set up at different angles and to work out a lot of little details which they always jibbed at before when one tried to get them to use nickel steel. I think the prejudice in the workshop against nickel steel has to a large extent disappeared.

MR. YOUNG: To the advantage of the industry? A. Yes.

DR. MILLER: And you think that attitude will remain? A. Yes. So much nickel steel is being mixed up with ordinary iron that everybody is getting familiar with it. It has been a very great education for engineers. We have a very good statistician in our statistical department and we have been trying to analyse the figures and see how we are going on, but the statistics are yet in such shape that you cannot make head or tail of them.

(Sir Alfred Mond): The gentleman specially employed for that work is working for the government at the present time. I think it may be laid down as a general proposition that the use of nickel for general civil purposes is undoubtedly largely increasing, but for armaments it is becoming less important than it was. I think that is the broad business proposition. These nickel goods (referring to some articles on the table) have been developed a great deal.

Q. They might be described, for the benefit of the notes, as light nickel ware? A. Yes. This one was made in Austria.

MR. GIBSON: Is the use of nickel steel confined to the armour-plate? Is is not used also in the structure of the ship? A. (Mr. Robert Mond): Very little, I think.

Prospect of Extending Uses of Nickel

(Sir Alfred Mond): Not much. I do not know myself what the position really is as regards steel rails. I think there might be some futuie in that direction, but up to now the experiments which have been made in America have not been very successful, for reasons I am not fully familiar with.

CHAIRMAN: We were told it was more because they were not concluded. Certain rails had to be pulled up, for instance, on account of structural alterations before they had been fully tested. A. It is a financial question. I should have thought that the use of nickel steel for electric traction lines like tubes would probably pay. The hammer of the car in electric traction is very considerable on the rail. You know how difficult it is to get people to lay down more capital than they need. Most concerns have usually less capital than they want, and anything which tends to increase capital outlay is as a rule difficult to introduce.

Q. Have you taken any active part in the manufacture of alloys, as the International have done with Monel metal? A. No, we never have.

Q. That type of alloy is a very interesting development. A. Yes. I do not know how far Monel metal is a success. It is not the success it was expected to be when I was first introduced to it in New York.

(Mr. Robert Mond): Monel metal at that time was really a measure for getting rid of the superfluous nickel.

Q. Yes, that is what they say? A. An alloy *ad hoc* could not have a very definite composition. They were practically selling it at copper prices.

Q. That is in the olden times? A. Yes.

(Sir Alfred Mond): I do not think they have pushed it very much of later years. The increase in the consumption of nickel of late years has been very gratifying. It had been a very slowly developing industry if you look at the figures. For many years it was a stationary business.

(Mr. Robert Mond): Then it would take a jump, and then remain stationary again.

(Sir Alfred Mond): The automobile business itself has of course given it a great development, and the aeroplane business has given it a certain development. I hope to see an extension of what might be called the high nickel content steels—20 to 30 per cent.

Q. We were at the National Physical Laboratory the other day, and we were talking about that. There is a suggestion of having research done on that matter. Of course that would be very important. A. (Mr. Robert Mond): Guillaume has done the best work on that.

MR. GIBSON: For what purposes are the high nickel steels used? A. The Guillaume "invar" alloys. It is rather an interesting thing: if you follow the heat expansion of these alloys you get a reversible point beyond which they contract with an increase of temperature, and "invar" is just at the turning point. It is useful for making measuring-tapes and so on because you can make a thing which is practically independent of temperature. That makes it very valuable.

MR. YOUNG: Would the use be very considerable? A. It is being used more and more for high-class measuring-tapes, also for the pendulums of clocks.

Q. But there is not much steel required for that purpose? A. No. There is a good deal of work being done on the higher percentage nickel steels in the American navy for boiler tubes. When you get up to a certain percentage you get incorrodibility.

(Sir Alfred Mond): Nickel steel is used a good deal more now in all kinds of machinery generally—parts of machinery.

[*Sir Alfred Mond; Robert Mond.*]

(Mr. Robert Mond): It is being used a good deal in turbines, and for making crankshafts and connecting rods, reciprocating machinery, and so on.

Q. Not very much nickel is used in light alloys, I think? A. No.

(Sir Alfred Mond): Of course nickel coinage will always go on absorbing a good deal, though we cannot get them to adopt that coinage in this country. If you look round this room, you will see we have an enormous number of samples of nickel coins. Practically every State has got them. That is a growing and a constant demand. A certain amount of the coinage gets lost and it has to be replaced. The Indian government is doing a good deal in that direction.

MR. GIBSON: Mainly in the form of nickel-bronze, I presume? A. I think the Indian is a nickel-copper alloy.

The Cost of Production

CHAIRMAN: Then we come back to the question of the cost of the different steps of the treatment from the mining and the smelting to matte, and the cost of the different steps for the process in Wales; how far could you give us information on those points? A. (Sir Alfred Mond): Do you want the separate divisions?

Q. Yes; for instance, the cost of producing a ton of matte and the cost of producing a ton of nickel, and of the copper sulphate and other products, from the matte. A. I will see what I can do. There I come back to the question of how far these figures are going to be published. I could not give you those figures to become public property. In fact, they are not quite easy, because of course as we make nickel and copper sulphate at the same time a division would be arbitrary. I think I could give you the figures for your purpose in a form that would suit you. We make nickel and copper sulphate simultaneously and a great deal of it goes through the same processes. For our own purposes we adopt what I might call a conventional kind of division of charges. It is quite conventional We could devise many other methods of doing the division; such as by tonnage or by value of product. I think I could give you the thing in a form which would give you the information you want.

Q. I notice one thing, for instance. In some figures which you have given of the amount of matte produced, you value the nickel at 15 cents a pound and the copper at 7½ cents. That is one of the arbitrary figures you mention? A Yes.

Q. It seemed rather low to me for the nickel, considering the market price; it would indicate that the cost of refining was very heavy as compared with that of smelting to matte. A. Well, of course it would be.

MR. YOUNG: The other companies stand in the same position in that respect; they seem to have adopted merely arbitrary figures? A. Yes. We tried to arrive at some relative value of nickel to copper, but it varies so very much.

CHAIRMAN: The relative expense in producing the matte is a thing which is very important to us as a Commission, and in refining the matte to metal. In your case, you get the precious metals; the International, except in certain parts of the process, do not. If they make Monel metal for instance, they all go in? A. Yes. They do not get them in the ordinary process at all. We have never looked upon the precious metals as any part of our costs or profit; we have looked upon that matter as a gift from God. You can never tell beforehand what you will get; you have no reason to assume you will get any; you do not know really whether you are going to have any more or not.

Q. It would almost pay you to make a market for palladium, would it not—to force it? A. I think events are making a market for it.

Q. You think that is going to be all right? A. I think events are making a market for palladium. The government having commandeered all the platinum, I think the jewellery trade is now being compelled to consider the question of palladium.

Q. Do they use it mainly as an alloy with silver? A. (Mr. Robert Mond): They have worked an alloy of silver and palladium which seems to be useful to take the place of platinum for sparking plugs and things of that kind.

(Sir Alfred Mond): We do not make our end products. We have really no control over the sale of these things. The people who handle them are very loath to give us any information.

Q. It is really the same as electrolytic copper, is it not? A. Yes. I always think these things find a market. They use it for photographic purposes, I understand—platinum bromide. It is used for dental purposes, too.

MR. YOUNG: Have we a clear understanding as to the figures the Chairman mentioned last, when we were discussing the arbitrary standard for matte? You will realize that our desire is to get accurate information as far as possible? A. Yes. There must be more or less arbitrary division. If you have to put a joint product through a process, you could adopt the division of half and half; it depends on how you like to book it. We adopt a division which I do not know is a very perfect one, but we have had it so long that we have kept it for purposes of comparison.

[*Sir Alfred Mond; Robert Mond*]

The Selling Price

CHAIRMAN: What we want is not so much the relative value of nickel and copper, as the relative cost of producing matte and of obtaining the nickel from the matte. If we take the market price of nickel, it is difficult to say what these relative costs are? A. What have you taken it at there?

Q. We are taking it at your own figures at 15 cents a pound—$300 per short ton in the matte. These are just taken from your ordinary basis. A. The normal selling price of nickel is about £135 to £140 per ton.

Q. You mean under pre-war conditions? A. (Mr. Robert Mond): Yes; the average all over.

Q. That would mean per long ton? A. (Sir Alfred Mond): Yes.

MR. YOUNG: We want the cost of the successive stages to the finished article. A. I would like to do the thing in as comprehensive a way as I can. I think these divisions would only mislead you, because they are necessarily so arbitrary.

MR. YOUNG: We like to view the subject from as many angles as possible, because our enquiry is comprehensive. A. Quite so.

(Mr. Robert Mond): Taking a cent to be a halfpenny, the figures would be about right.

(Sir Alfred Mond): I do not mind saying that the profit is very considerable, as appears from our balance sheets; only, of course, we deal with such fluctuating factors. Copper sulphate is perhaps £16 a ton one year, and £28 the next.

MR. YOUNG: We are not concerned in the enquiry as a mere matter of curiosity. It is awkward for us to press certain questions; but on the other hand, when we are dealing with the whole nickel situation, we want to get all the information we can. A. I know.

Q. Therefore we would be very grateful for the most detailed and accurate information you can give us. A. I will endeavour to do my best to meet you in that. You quite realize my difficulty—the difficulty of disclosing very confidential information and putting it in a form which will be useful to you. Of course we can give people figures, but unless it is understood how they are arrived at they are very often apt to mislead them rather than to inform them.

MR. YOUNG: My technical colleagues can make our requirements more intelligible to you than I am able to do.

CHAIRMAN: Mr. Young has put it very clearly from the general point of view.

MR. GIBSON: There is very little matte sold in Canada? A. That is so. We have purchased matte at different times. We have bought some blast-furnace matte.

(Mr. Robert Mond): When we first went out there, we tried hard to get people to make matte and sell it to us.

(Sir Alfred Mond): I know they wanted much higher prices for matte than we have put down there when it was a question of buying any. I think I should explain that we do not arrange our accounts so as to show any profit on our mining enterprise. If we did, these costs would be very different. You might arrange your costs so as to show certain profits from your mining enterprise, as selling to the refining works. It is easier for the International because they are organized as separate concerns. I do not know whether the Canadian Copper Company sells to the New Jersey Company, or whether they do not. We simply treat the whole thing as one concern, and the end profit. Our matte costs would appear relatively lower than they could possibly appear if somebody was carrying this thing on as an enterprise in which he was endeavouring to sell matte so as to make a profit, and cover the depreciation of his mining property.

MR. YOUNG: He would make a profit on the matte? A. Yes; he would want to add a considerable sum to that.

Q. Your method is really better for our purpose? A. It may be better for your purpose. We make additions for depreciation here which are not made at the mine—writing off and that kind of thing. That also is on a rather arbitrary basis, because those things are arbitrary; you cannot lay down any very definite basis, but you can lay down some basis.

Nickel Deposits in Other Countries Available

CHAIRMAN: I suppose you do not buy or wish to buy the New Caledonian matte, on account of the absence of copper? A. Well, we do not want to buy any matte because we have plenty from our own mines, which certainly pays us better than buying other people's matte. The only ore we bought was some Tasmanian ore.

Q. That is very rich, is it not? A. Yes, there is some very rich ore there.

DR. MILLER: Is that comparatively recently? A. Yes.

CHAIRMAN: That is from the Zeehan district? A. Yes, from that district. They are very rich ores.

Q. With regard to the properties in Madagascar, we received a report concerning them, I think; is there anyone in London who has seen those parcels, from whom we could get any further information? A. I do not know. We have a certain amount of

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information on the subject because the properties were offered to us. We had the information which the people had. There has not been any real work done. There appeared to be a very large and important silicate deposit there. It is some distance from the railway.

(Mr. Robert Mond): They want a new railway and a new harbour development, and all that kind of thing. It is probably one of the reserves of the future.

(Sir Alfred Mond): There is a great deal more nickel ore in the world, I think, than we have any idea of. I understand there have been some very interesting finds made recently near Port Arthur.

MR. GIBSON: In Ontario? A. Yes.

DR. MILLER: Reports have come from there, but I do not think they have been confirmed. You are getting ore now at Coniston? A. Yes. Fifteen bags of ore were received from Mābella, a station west of Port Arthur. We regularly receive nickel ores from the Alexo mine in Dundonald township.

Q. I suppose this ore works in well with yours, because it is a similar kind of ore? A. Yes.

CHAIRMAN: We are told the Tasmanian ore is 10 per cent. or 11 per cent. That is very rich? A. Yes, it is a very rich ore. What quantities there are and what importance the deposit has, I really cannot form a real opinion upon. I have never had time to send anybody to investigate it seriously. One cannot buy all the nickel mines there are in the world. The Norwegian mines have been benefiting by this war very considerably; a number of propositions there which have been shut down have been re-opened and developed again.

(Mr. Robert Mond): We have examined a whole series of them.

(Sir Alfred Mond): I have here two books full of descriptions of mines which we have examined in different parts of the world—something like several hundred.

(Mr. Robert Mond): I think we have over 500 in these two books which we have had reports on.

Q. We must not ask you for those for publication. It would be too much. A. (Sir Alfred Mond): I think the information on the whole is less confidential than some of the information you have asked me for. I have no doubt a good deal more nickel ore will be found in different parts of the world if it is wanted.

Difficulties of Electrolytic Refining

Q. (To Mr. Robert Mond): There was one question I was asking Sir Alfred at the beginning, namely, how far you had gone into the matter of electrolytic refining, and he said you would be able to give us more information.

(Mr. Robert Mond): The man who did the most work on electrolytic refining was Dr. Karl Hoepfner. My father and he and I have worked a lot together. We did electrolytic zinc refining together, which they are working up in Cheshire. It was on zinc chloride. He was an extremely ingenious man; he was always inventing something. He had a fairly big research laboratory in Germany, and worked all kinds of things out there. One of his nickel processes is being worked at Pappenburg, close to Emden in Germany, by one of his former assistants, Dr. Savelsberg. We have also worked out several other ways of doing the thing. We have always found it was possible to work the thing out electrolytically, but it was a more expensive method than ours. We wanted to assure ourselves of that. We went into these things to see whether the electrolytic process would be any technical danger to our process.

Q. Suppose you based it on the cost of electric power at $15 or less? A. The cost of electric power is a minor detail.

Q. About 25 or 30 per cent., I suppose? A. Yes. The great question in all these things is how successfully you can avoid liquor losses. Your liquors become very valuable. You have to take them through a lot of refining processes and you always get impurities accumulating. One of the great difficulties in the electrolytic process is that in order to get a good product you have to work with what is, from the electrolytic point of view, a chemically pure solution. That does not mean there may not be a variety of bodies in it, but there are a number of bodies which have to be kept out. That is always a much more expensive procedure than anybody calculates on, and it has always been the bugbear in all these things. You may find traces of arsenic or manganese and things of that kind turning up, and you have to get them out; and you have to devise new analytical methods for finding out that they are there before you can get them out. Such things being present to the extent of 0 01 or 0.001 per cent. makes all the difference between a good and a bad deposit.

Q. In the last two or three years the advances in that respect have been so enormous that they have rather altered the aspect of the electrolytic treatment—I mean for copper and zinc, and probably also for nickel. A. With copper you generally make from pure blister copper to start with, and take it from one plate and put it on another. That is a different process from getting the metal out of a solution.

Q. The Anaconda are doing it from the solution now? A. Yes. You generally find you have to get up fairly high with your voltage if you want to keep capital expenditure

[*Sir Alfred Mond; Robert Mond.*]

down. You have to work with a minimum potential of 3 volts, and you generally find yourself with an actual potential of about 5 volts or so, so as to keep down the volume of the copper-conducting things. With anything of that kind you find the amount of work you do per unit of electricity diminishes very rapidly. Take a kilowatt, with 1,000 amperes in it; if you work at 3 volts you can get 333 amperes out of it; if you are working at 5 volts you can only get 200 amperes out of it. If you could work at 1½ volts, or at 1 volt, as they do in ordinary copper refining, you could get 1,000 amperes out of it. As you increase the voltage, you want two or three times the horse-power at once.

MR. YOUNG: The Chairman's question was whether advances had not been made. It is the fact, I suppose, that they have? A. I cannot tell you very much about the most recent advances.

CHAIRMAN: In Ontario, where we have electric power cheap, and where it will be possibly still cheaper later on, electrolytic processes are of very great interest to us. A. Naturally.

Q. We have to go into the matter extensively in our enquiries and in the report. A. One of the difficulties in all electrolytic processes has been this:—If you have a fairly concentrated solution it is comparatively easy to fetch out about two-thirds of the metal in the solution; the difficulty is to get out the remaining third. You have to work it up over and over again. This has been one of the fundamental difficulties. There is no difficulty in electrolysing a solution which contains 4, 5 or 6 per cent. of the metal, but when you get down below 2 per cent., then it is difficult. Then you begin oxidizing it, and doing all kinds of performances with it.

(Sir Alfred Mond): I do not know whether you want to ask me any questions about taxation?

CHAIRMAN: That would be a very interesting matter, if you have the time. Are there any other technical questions?

DR. MILLER: It seems to me that if in a couple of weeks or so we could again meet Sir Alfred Mond, that would be the best thing.

CHAIRMAN: That would be most excellent. We will send you a copy of the transcript of the shorthand notes and then you will have a chance of looking it over. A Certainly. I shall be very much obliged to you.

DR. MILLER: I thought something might occur to you in the meantime, Sir Alfred. A. I shall be very pleased to meet you again. I do not know whether arrangements have been made for you to visit our works at Swansea.

CHAIRMAN: Yes, through this office; so far as I know it is all definitely arranged. A. I am very glad indeed for you to see them.

MR. YOUNG: Could we get an approximate date for our next meeting? A. If you will give me some alternative dates, I will do my best to suit your convenience.

Evidence of Mr. Robert Mond and Mr. Robert Mathias, Directors of the Company

(London, England, 27th April, 1916)

CHAIRMAN: Before we begin, I would like on behalf of my colleagues and myself to express our regret at the accident to Sir Alfred Mond, and for not being able to meet him to-day. I suppose he has gone over the evidence he gave us the other day, with the view of making any necessary corrections. A. (Mr. Mathias): Sir Alfred has looked through his evidence and has made a few corrections. They are very few.

(Mr. Robert Mond): I have made a few also. The principal thing is that we have expanded our information with regard to our relations with Messrs. Merton so as to make the matter quite clear.

(Mr. Mathias): Mertons acted as our metal brokers.

(Mr. Robert Mond): Mertons had perhaps the highest reputation as metal brokers in this country. They were always treated as such by the Government and everybody else.

MR. YOUNG: We have heard somewhere that anyone who wanted to buy nickel was invariably referred to Mertons—that your company and other companies would refer people to Mertons and would not sell directly to them. Would you necessarily refer anyone to Mertons? A. (Mr. Mathias): Yes. They were our brokers. But not now.

Q. I think Sir Alfred has already told us that every arrangement is terminated? A. Yes.

Q. Is that arrangement which he mentioned with some of the other nickel concerns whose names he did not care to disclose also terminated? A. Yes; we have no arrangement whatsoever. There are various matters we can give you information about, but I do not think we are at liberty to give you that information if it is going to be published.

Q. There may be some points on which you would be glad to give us information. A. (Mr. Robert Mond): We would be pleased to give you the information, only we cannot do it very well without the permission of the other people.

[*Robert Mond; Robert Mathias.*]

Q. Quite so. On reading Sir Alfred's statements over, I find they are very largely negative. He has told us some features which were not within the operation of this arrangement with the other companies, but we would be very glad to get any additional information you might feel at liberty to give us. A. (Mr. Mathias): There is no arrangement with any other firm at the present time.

Special Price for Armour=Plate Makers

Q. Was there not an arrangement between all the companies for many years? A. I do not remember what Sir Alfred referred to, but I think it would only refer to the armour plate people, with regard to a special price.

(Mr. Robert Mond): When we started operations we found the main consumption of nickel for armour-plate was practically by a close syndicate, with whom we found very great difficulty in getting into touch.

Q. In order to sell your goods? A. Yes, in order to sell the goods at all.

(Mr. Mathias): They threatened at one time to acquire their own mines and refine their own nickel.

Q. Was that a syndicate of armour-plate manufacturers? A. Yes.

(Mr. Robert Mond): You might call it an international syndicate of armour-plate manufacturers.

Q. It was not an association of producers of nickel? A. No.

Q. Was there ever any arrangement between the producers, such as the French Nickel company and the Mond Company and the International Nickel Company for controlling prices? A. (Mr. Mathias): No. All that happened was that the other armour-plate companies had a contract with the French company at a certain price, and we agreed to supply them at the same price.

Q. You agreed to supply the armour-plate people? A. Yes.

Q. Was that arrangement in writing or was it a verbal understanding? A. That I do not remember; it is so long ago. It was an understanding.

Q. Of course we have no desire to be unduly curious, but it is important that we should get all the information possible as to the facts. A (Mr. Robert Mond): We had a great free fight in order to try and force Canadian nickel—to get an outlet for it.

(Mr. Mathias): The armour-plate people would not use Canadian nickel at all; that was the position we had to face.

(Mr. Robert Mond): And the Admiralty would not use Canadian nickel. They told us it was no good at all. That was the first thing we had to break down

Q. Is there any such combine at the present time? Leaving out of account the Mond Company, is there any combine or association of producers which is affecting the output or supply of nickel? A. No, I do not think so. The arrangement, which was an international one, has automatically come to an end.

Q. You think the war put an end to it? A. (Mr. Mathias): It had to.

Q. But of course the war would not affect those companies that belong to the Allies, like the French company and the Mond Company or the International Nickel Company which is in a neutral country? A. (Mr. Robert Mond): No; I am talking of the armour plate people.

MR. YOUNG: I had in mind the rumours that are abroad in Canada and in the United States, and possibly here, of an association of producers of nickel. A. (Mr. Mathias): We cannot at the present time say how those agreements stand, we cannot say what arrangements the armour-plate people have with the Government

Now Unrestricted Competition

Q. Just for the moment, I am not concerned with the armour-plate people, but with the producers of nickel having an arrangement with regard to prices; is there any existing arrangement by which competition between the producers is either prevented, controlled, or regulated? A. There is not.

Q. Was there ever one? A. (Mr. Robert Mond): The point is, whoever can supply the nickel at the present time will get the orders.

Q. There is nothing to control competition? A. (Mr. Mathias): No. The point is, can we supply more nickel? We have been asked to supply more nickel, but we cannot; so other people have to get the orders.

Q. That is so; that is the ordinary course of trade? A. Quite so.

Q. But is there at the present time anything to prevent your underbidding the French company or the International Nickel company? A. (Mr. Robert Mond): Nothing whatsoever.

Q. Do I understand that there was such an arrangement prior to the war? Do you know, or do you care to tell us, whether that was or was not the fact? A. (Mr. Mathias): That is quite true. Other people supplied at a certain price, and we agreed to supply at the same price in order to get our nickel in.

[*Robert Mond; Robert Mathias.*]

Q. In other words, I understand you to say you found a condition of affairs which precluded you from your fair share of trade unless you joined an association which was then in existence? A. (Mr. Robert Mond): Exactly; that is what it came to.

Q. And you joined it? A. Yes.

(Mr. Mathias): We agreed to supply the armour-plate people, the Steel Manufacturers' Nickel Syndicate.

Q. At a fixed price? A. (Mr. Robert Mond): Yes.

Q. Were they long term contracts? A. Yes.

(Mr. Mathias): We have no contracts now.

(Mr. Robert Mond): Not now, but there were long time contracts; the armour plate people made long contracts.

(Mr. Mathias): We have no contracts whatsoever with them, now, with regard to the supply to-morrow; we only agreed, in order to get our share of the business, to supply them at the same price as the other people did.

Q. Who fixed when the price should be changed? Upon whose decision did the price depend? Upon a committee of the Syndicate? A. (Mr. Robert Mond): You had better see the armour-plate people. Mr. Vickers is the principal man.

Q. That is not my point, because after all, the armour-plate people are purchasers? A. (Mr. Mathias): Yes, but they made a contract long ago.

Q. With whom? With this Association? A. No: I understand it was with the French company.

Le Nickel at First Predominant

CHAIRMAN: With Le Nickel? A. Yes.

MR. YOUNG: That may clear the situation. Is it an alleged arrangement of which we have heard between the French Nickel company and certain armour-plate people that you have in mind now? A. (Mr. Robert Mond): Yes, that is it.

Q. That arrangement took this form, as I understand it, that the French Nickel Company, the Société Le Nickel, made some arrangement with another company called the Anglo-French company, by which the Anglo-French company would refine their nickel in this country, and the Anglo-French company's shares were to be held by the great armour-plate houses? A. (Mr. Mathias): Yes. I can give you the information about the Anglo-French company.

Q. I can get that from the ordinary sources. A. I have it here.

Q. We would be very glad to get anything that you have. A. (Mr. Robert Mond): You must remember that Le Nickel were the first in the field, of course, and they were the principal producers of nickel. It took the International company a long time to become an important factor in the nickel market at all, or rather, I should say, before they were the International, it took Col. Thompson a long time to become an important factor. Le Nickel for a great number of years practically controlled the whole of the nickel output. We started just about the time Col. Thompson was becoming a more or less important producer. They had gone ahead faster than we had. They had the Creighton mine and we had not. McConnell sold the Creighton mine to the International, and he sold us the other mines. It was quite a question of pitch-and-toss to whom he would sell either. Nobody knew anything about the Creighton mine.

Q. You were going on to say that when you got into the trade you found the International company had made some advance in fighting Le Nickel. A. They were fighting at the time. Just at that time, you may remember, Col. Thompson sold a large amount of nickel to the American government at a very low price.

Q. Thirty cents a pound? A. Yes, for armour plate making. That was at the time when he was in the middle of the fight, and he could not get rid of his stuff at all. He was very pleased to find somewhere it could go. You have to take that into account together with the consumption of nickel; and you will find the consumption of nickel has, till comparatively recently, been extremely unsatisfactory. It would rise, and then remain steady for three or four years, so that any additional works which were put up in anticipation of that rise suddenly found themselves with nothing to do.

Q. In other words, Le Nickel completely controlled the trade until the International got strong? A. Yes.

Q. Then when you got strong, you came in as a competitor? A. Yes.

Q. And then competition was regulated by an arrangement or understanding between the three companies? A. The other people had an agreement, and we agreed to supply at that price in order to get rid of our nickel.

Q. To supply under their agreement? A. Yes, to supply at the same price.

Q. At the same price, and select your own customers? A. The agreement was with the armour-plate syndicate.

Q. Armstrong, Whitworth's were not concerned in that? A. Yes, they are.

CHAIRMAN: They are now, but were they at the beginning?

[*Robert Mond; Robert Mathias.*]

MR. YOUNG: They were never shareholders in the Anglo-French company? A. They are members of the Steel Manufacturers' Nickel Syndicate.

Q. Are they in the published list? A. I really do not know, but I can find out, and I will do so.

(Mr. Robert Mond): The armour-plate people managed to get favourable terms out of the nickel manufacturers, because they had their own mines.

Q. What mines had they? A. In New Caledonia, and they threatened them with that ore. That is really the factor which conditioned the terms on which they got their nickel.

Q. They were holding out against the Canadian mines the bugbear of New Caledonian ore? A. They were fighting New Caledonia with New Caledonian ore. Le Nickel was the biggest producer. The time I am speaking of is not very long ago, but it is a long time in the history of nickel—quite fifteen years ago.

Price to Ordinary Consumers Not Controlled

Q. Did that price to the armour plate people by the French company necessarily control the price to other consumers? A. (Mr. Mathias): No, it did not.

Q. The ordinary purchaser of nickel, not for armaments, could deal with any of them? A. Yes, through the selling agents.

Q. And they could quote him any price they liked? A. Yes. We could not deal with the armour-plate people.

Q. But only at a fixed price? A. As they had a contract already, what was the use of doing otherwise?

Q. Their wants were contracted for at a fixed price? A. Yes.

Q. You must not construe what I am saying as an attitude of hostility; but we are trying to clear up this thing as well as we can, and we are grateful for any precise and accurate information we can get. A. (Mr. Robert Mond): Neither of the governments had any armour-plate plants of their own. The government consumption of nickel was for coinage more than for anything else. On the outbreak of war we offered to place the whole of our make at the disposal of the government. It took them six months to find out whether they wanted it or not. They did not know that they wanted any. They said the Admiralty did not consume nickel.

(Mr. Mathias): I find that you are right, Mr. Young, about Armstrong, Whitworth's; they are not members of the Anglo-French company.

Q. Nor are Hadfield's? A. But Hadfield's are not armour-plate makers.

Q. But they are purchasers of nickel? A. Yes.

(Mr. Robert Mond): Yes, they are purchasers of nickel.

Q. This is a copy of the shareholders' list which is filed pursuant to the Companies' Act, that has been handed to me. It corresponds with the result of my own enquiries. When you finally got into the arrangement, I suppose it was worked through the agency of Mertons as selling brokers? A. (Mr. Mathias): At that time?

Q. Yes; or was there an arrangement between the Mond company and any other company? A. We supplied to the members of the Steel Manufacturers' Nickel Syndicate.

Q. Is that an incorporated company? A. Yes.

(Mr. Robert Mond): Mertons acted more or less as general accountants.

CHAIRMAN: I see most of the corrections made in the evidence given at the previous sitting are merely verbal. There is one thing I should like to refer to. Sir Alfred said, "I was going to ask you this—I am sure you will not mind my putting the question—how far are these figures going to be published?" Naturally we did not like to promise too much, but you can safely take it for granted that we shall not publish anything which would give information to other people which is not justifiable, and that anything you tell us in the way of details of costs will be absolutely confidential to us and to the Ontario government—the Ministry of Lands, Forests and Mines. We naturally wish to avoid publishing anything which is not what might be called of general interest—I mean useful to everybody and that everybody would wish to be published.

The Question of Costs

MR. YOUNG: Of course the question of the costs with regard to nickel is extremely vital to our enquiry. A. Naturally it is.

Q. But we are not going to embarrass any company. A. We should like you to be in a position to have such figures that you could adequately compare for your own purposes the relative value of different processes.

CHAIRMAN: That is what we want. A. Of course we do not want other people to know them, but we want you to have those figures.

(Mr. Mathias): We cannot allow these figures to be published. You know it would be absolutely suicidal to any company to publish those figures. You know that yourself.

[*Robert Mond; Robert Mathias.*]

Q. Yes. I think it is clear that we are anxious, exactly as you are anxious, to have all the information that we can get, but only to publish what is absolutely justifiable. A. I will hand you this information. We are willing to give you any information if it is to be confidential.

Q. The best plan would be for you to give us the information and say, "Such and such portions are confidential, but we are quite pleased that you should publish the broad statements about so and so." That would be the simplest plan, I think. A. (Mr. Robert Mond): Yes.

MR. YOUNG: As Mr. Mond suggests, we have got to use facts in order to make comparisons, in general terms. I do not see how that can prejudice your company. As Mr. Mond suggests, we are entitled to know what processes are the cheapest for producing nickel, and I think we might say so publicly. A. (Mr. Mathias): There is no harm in that, I think.

CHAIRMAN: We know that certain departments of your process are not only absolutely sound metallurgically, but also obviously very economical. A. Yes.

MR. YOUNG: It is quite possible for us, as it is for your competitors, to get a fair idea of the costs from our own enquiries, calculations and computations, but it is much better for the sake of accuracy, in which we are all interested, that we should have definite information. A. (Mr. Robert Mond): Of course. I know a great deal about drawing up costs statements in different works in different couutries.

(Mr. Mathias): The only figures you are interested in really are the pre-war figures; you do not want the figures of the present time?

Q. We do not want abnormal figures; no. A. The present figures are abnormal.

(Mr. Robert Mond): We are trying to work out a costs statement on pre-war lines for you. We have got it roughed out, but we have to go into details to see that we are agreed upon them.

CHAIRMAN: That is why we are anxious to get the real figures, because we are always having figures volunteered and offered to us, and we do not want them, because we do not know how far we can rely upon them. A. (Mr. Mathias): I quite understand.

MR. YOUNG: And it is quite possible for people to volunteer figures about the costs of the Mond process, and if they are not corrected by definite information, it puts us in a bad position. A. (Mr. Robert Mond): Of course it does. There are great difficulties in getting a real costs statement, because the costs statement one works with technically is never a real one; it never includes a sufficient proportion of general charges, depreciation, and other things. You never put them into the costs statement, and consequently, one has to draw up a costs statement on new lines for a thing like this, so as to give the kind of figure the work would cost somebody else who started anew with our experience. That is what we want to get at as near as we can.

Q. In the statement you are preparing, you are keeping in mind what Sir Alfred was good enough to intimate, namely, that he would give the successive stages? We want to have a comparison of the cost of making the matte and of refining the matte. A. Exactly. You have the cost of the matte, and now we are working out the cost of refining the matte and what the two together work out at.

The Precious Metals

CHAIRMAN: I have a note to ask you with regard to both production and costs. Could we have them for copper sulphate, nickel sulphate, nickel metal, and the quantities of each, and the different stages that you were mentioning, and also the precious metals in the residues. I understand you do not refine the precious metals, you dispose of them, I was going to say as waste, though of course they are worth a good deal of money. A. (Mr. Robert Mond): With regard to the precious metals, there is one great difficulty in trying to give you anything definite, and it is a very simple one; in the extraction of nickel and copper from the ores by the usual method, it takes a certain number of processes before we get the remaining matte up to a certain concentration, before it goes into the leaching processes for removing the final amount of nickel and copper, and the consequence is the operation extends over very long periods. I believe the first time we ever got our precious metals was after seven years' working, or something of that kind. We came to the conclusion that the only rational method was to do the thing by batches—to start with a certain number of thousands of tons of Bessemer matte and deal with that as a definite batch.

Q. That will suit us, because we do not want to know what was produced in a certain month or even a certain year. In the descriptions which have been published, Roberts-Austen's, for instance, and that by Coleman, there is no mention of the precious metals worth talking about? A. When Roberts-Austen wrote he did not know we were getting any.

(Mr. Mathias): You know it was first intended to treat by this process New Caledonian ores. I do not know whether there are any precious metals in New Caledonian ore or not.

Q. They are not worth counting, I understand? A. The cost of refining one ton of nickel by our process will be much cheaper in the case of New Caledonian matte than in the case of Canadian nickel-copper matte.

[*Robert Mond; Robert Mathias.*]

Q. You were going to give us a statement which we could publish as to your process, and if you could put in something about the recovery of precious metals it would make it complete. It has never been done before so far as I know. A. As a matter of fact, we do not recover them.

Q. I do not know at what stage you obtain the mud as they do in the electrolytic process for copper. It lies in the bags and they sell it for its assay value, just as they would sell in in the first instance, only it is rich instead of being poor. I presume you assay the matte and not the ore, and then you sell the products. But all you are interested in is what you get, because the assays must be more or less unreliable on the original material? A. It is really an accumulation. You saw the works, and you know how long it would take before one got to finality.

Q. Can you give us an estimate which will cover any credit to which the process is entitled? A. Yes. There is one very peculiar thing about these precious metals—

MR. YOUNG: Sir Alfred said it was a gift that God gave you. A. Yes. We find the larger the ore deposit, the less the precious metals, roughly speaking. You may have small, poor, rocky ore deposits which have practically none at all.

Q. It is a matter of average over long periods, is it not? A. Yes.

(Mr. Mathias): There are no reliable figures as regards how much each matte contained.

(Mr. Robert Mond): We cannot get them. If we tried to make a rock analysis it would take about six weeks, and the quantities would be so small that one would not know how much reliance could be put on it. It is an impossibility to make a systematic set of analyses.

MR. YOUNG: So far as I am personally concerned, what I want is to ascertain the cost of a pound of nickel by your process after giving credit for your copper sulphate and precious metals, if they are entitled to credit, or any other benefits which you realize on the ore. A. We can give you figures which will enable you to do that. But the precious metals are terribly misleading, in this way, that you get one mine which may be much richer than another, and that may send up the average of the whole lot.

(Mr. Mathias): Or one ore pocket may be particularly rich.

(Mr. Robert Mond): Yes. You could not apply such figures to another nickel proposition. It may be there, or it may not be there. It may be much better, and it may be much worse.

Q. I understand you only get the nickel product, copper sulphate and some precious metals? A. Yes.

CHAIRMAN: Do you make any metallic copper? A. No.

Q As regards your statistics, when it is stated that the Mond Nickel Company produces so much nickel, does that mean so much metallic nickel, and then in addition so much nickel sulphate? A. (Mr. Mathias): Which statistics do you refer to?

Q. I mean any statistics which may be published—for instance, in the Canadian statistics? A. It is only the nickel contents of the matte. In every metallurgical process you get a loss.

Q. I should imagine you have less loss in your process than there is in others? A. (Mr. Robert Mond): But there are always losses.

Q. We were very much impressed with your plant when we looked over it. A. It is a remarkable plant. It does not look a bit like a metallurgical works, does it?

MR. YOUNG: It is very impressive to a layman.

CHAIRMAN: Sir Alfred promised to give us a memorandum amplifying the evidence he gave us; will it be long before that is ready? A. (Mr. Robert Mond): We wanted to give you an additional memorandum, which we are now drafting.

MR. YOUNG: My recollection was that he promised to give us the annual reports of the company? A. We can give you these now.

MR. YOUNG: And a copy of the list of your shareholders which you file with the Registrar of Joint Stock Companies? A. (Mr. Mathias): There are about 5,000 shareholders. We can let you have a list, of course.

(Mr. Robert Mond): We always make it up in July, and we can make two while we are about it. I think that is the best plan.

MR. YOUNG: And at the same time you could give us a copy of the balance-sheet which is filed at Somerset House? A. Yes. Would you like them for the last five years?

Labour in Wales and in Canada

MR. YOUNG: It would be very nice to have them for the last five years? A. (Mr. Mathias): One of the particulars you wanted was the wages in Canada and in Wales

Q. Yes, or rather the percentage of each. A. The salaries and wages in Canada you have got in your information; Mr. Corless gave it to you. Taking the same output, 5,000 tons of nickel, the proportion of wages and salaries is £300,000 in Canada to £100,000 here.

CHAIRMAN: How much labour is there, relatively, employed in Wales? A. At present we are extremely short. A number of our men enlisted, and we are trying to fill their places. We have been increasing all the time. We have a new shed started and we have got people in train for that. It takes about 250 per shed.

[*Robert Mond; Robert Mathias.*]

MR. YOUNG: And how many sheds are there? A. We have three running, and we are starting a fourth. That does not include yard labour and artisans and other people outside, you know.

Q. Nor does it include the executive staff? A. No. The executive staff does not grow in the same ratio as the increase of works.

(Mr. Mathias): The exact figures of those employed in Wales is 1,176.

Q. At what date? A. To-day, or yesterday.

Q. Is not that a little abnormal by reason of the war? A. We had 850 at the outbreak of war.

Q. Does that cover yard hands? A. (Mr. Robert Mond): That covers everything.

Q. What makes the difference of 300 men? A. Because we are getting ready to start a fourth unit.

Q. When that is operating, how many more men will it take? A. That will take this increase. We have to train them before we can start. As a matter of fact, we find it takes about two years to train a man. We are working with three shifts of about 80 per shift.

CHAIRMAN: What would the output be in 1916? Have you any idea? A. The new shed ought to make between 1,000 and 1,500 tons.

Q. And that will mean a total output of how much? A. About 5,000 tons.

Q. That is in metal? A. Yes.

Q. And in addition to that there are the copper sulphate and the nickel sulphate? A. Yes.

(Mr. Mathias): Why do we not make these things in England? (Pointing to a nickel bowl on the table.)

(Mr. Robert Mond): The English market is nothing compared with the Continental market.

(Mr. Mathias): There is scarcely any sale for them here.

MR. YOUNG: Would you have any objection to giving the scale of wages for England? A. We have already given it to you.

CHAIRMAN: I could not remember it. It would be well to have it, seeing we have got it for Canada? A. We gave you the difference. The cost of labour in Canada per man per day averaged about 10 shillings; the cost at Clydach averaged about 5 shillings.

MR. YOUNG: The average cost of a man in your refinery at Clydach is 5 shillings per day? A. It was before the war.

Q. That is taking high and low together, and striking an average? A. Yes

CHAIRMAN: I am inclined to think that that is as much as we want? A. (Mr. Mathias): Of course the freight rates are upset now. Instead of £2 10s. we have to pay £6 or £7 for matte from Canada.

MR. YOUNG: We are trying to arrive at conclusions based entirely on normal conditions? A. Yes.

(Mr. Robert Mond): In some cases, in order to get labour we have to pay the men 16 shillings separation allowance for their families.

Q. Taking the 1,100 men you now employ, what would be the increase in wages which you would pay if they were all transported to Canada? A. Double.

CHAIRMAN: We can put down that the cost of labour in Canada in connection with the refining of matte would be double that in Wales. Is that it? A. Pre-war.

Q. Under pre-war conditions? A. Yes.

MR. YOUNG: We have never had any refining in Canada; we do not know what the cost of labour would be? A. It is wonderful how the ratio of 1 to 3 has kept constant.

Q. Do you mean in the number of men employed—that, where you require 3,000 there, you require only 1,000 here? A. No, that is not it. It is more the relation of wages. The ratio of men is 1 to 2; the ratio of wages is 1 to 3.

MR. YOUNG: Have you looked into the costs of New Caledonian ore to the finished product? A. (Mr. Mathias): Not lately.

Q. Do you feel in a position to give us an idea of the cost of producing it? A. It is very difficult.

(Mr. Robert Mond): It is. For many years the French had a very heavy shipping bounty which enabled New Caledonian ore to be brought over in sailing vessels at a comparatively low price.

Q. It was a subsidy, in fact? A. Yes. Their shipping bounty was stopped a few years ago. They tried to counter that by erecting furnaces in New Caledonia—they make their matte there now—and using the same ship to take out a cargo of coal or coke to New Caledonia, and to come back with matte and nickel ore as a return cargo. I do not know how that has affected things. I think we came to the conclusion before that that it was unlikely that the price of nickel in New Caledonia would work out at less than one shilling per pound. It might be eleven pence or one shilling under pre-war conditions. But I have no data to tell me exactly whether this present arrangement may not have added a couple of pence to that.

MR. YOUNG: Would you put it in this way, that the enquiry had this satisfactory result, that it fixed minimum prices for Canadian ores? A. Yes.

[*Robert Mond; Robert Mathias.*]

(Mr. Mathias): You have been to the Anglo-French Company's works in Swansea, where New Caledonian matte is refined over here?

(Mr. Robert Mond): They have another works at Glasgow and another at Birmingham.

Nickel Works on the Continent

CHAIRMAN: And one in Westphalia, have they not? A. (Mr. Mathias): Yes, they had one.

Q. At Iserlohn. A. (Mr. Robert Mond): There was a works near Antwerp; there is not much of that left, I expect.

Q. That was Ballande's place? A. Yes.

MR. YOUNG: Are you in a position to give us accurate information with respect to the German refineries and works previous to the war? A. We could tell you something about it. The most important deposit of nickel in Germany is the Frankenstein deposit in Silesia. We had an interest in it a good many years ago. It is a very low grade garnierite containing about 2 per cent. of nickel. It was taken over by Krupp, and then he started refining New Caledonian ores there. Why he should do that in Silesia was a thing I could never understand. I think it was to mislead the German public as to the value of the mine or something.

(Mr. Mathias): They are still refining there. They make nickel there.

(Mr. Robert Mond): I have been over the place several times.

Q. What was the output in the old days? A. About 200 to 400 tons. The only other refining works were the French Company's works in Westphalia at Iserlohn.

(Mr. Mathias): There were three or four works which refined the nickel oxide.

Q. Where were they situated? A. On the Rhine, one in Westphalia, and another one at Pappenburg, near Emden. Krupp owned the works in Silesia, and they had about 5,000 tons of nickel as war stock in New Caledonian ores.

CHAIRMAN: He had some big properties of his own in New Caledonia, had he not? A. Yes.

(Mr. Mathias): After the war began Sir Alfred Mond made a confidential report to the British Government about the nickel business.

Q. With special regard to stocks of nickel on hand? A. Yes, and sources of nickel supply for Germany.

(Mr. Robert Mond): Then of course they are getting a certain amount from Norway and Sweden.

CHAIRMAN: I suppose the bulk of the Norwegian production goes to Germany? A. Yes, it all goes there.

Membership of Steel Manufacturers' Nickel Syndicate

MR. YOUNG: Could you amplify this statement with regard to the Steel Manufacturers' Nickel Syndicate a little? This is a company incorporated in England with 2,000 ordinary shares of £1 each and only 1,625 shares have been taken up. Who is Captain Tresidder? With what concern is he connected? A. I really do not know.

Q. Then Krupp of Essen; is that the armament maker? A. Yes.

Q. And Schneider & Co. of Le Creusot? They are French armament makers.

Q. Who is Dillinger Huttenwerke? He is a German armament manufacturer.

Q. Then the Société Di Terni? A. They are Italians.

Q. Then there is the Austrian, the Witkowitzer-Bergbau und Eisenhutten? A. Yes.

Q. Then the Cie. des Forges de la Marine, St. Chamond. They are French iron makers? A. Armament makers.

Q. And the other one, the Cie. des Forges de Chatillon-Commentry of Paris? A. Yes.

Q. Hadfields, and William Beardmore & Co we know. A. Yes.

Q. Then there are seven names beginning with Herbert Rich. A. I think those are the seven clerks who signed originally.

Q. They are the seven original shareholders. A. Yes.

Q. This Nickel Syndicate was the concern through which the sales you mentioned were really directed? A. Yes.

Q. And the French Nickel company had a contract with these people? A. Yes; they bought the nickel. I do not know that that Syndicate exists now under present circumstances.

(Mr. Robert Mond): I think it is very doubtful.

Q. The Italians and the Austrians are not in harmony at present. A. No

Q. Will you tell us the arrangement they had with their members? A. (Mr. Mathias): As far as I know they wanted to start nickel works, nickel refineries, and they combined for the purpose of supplying their own nickel.

(Mr. Robert Mond): They wanted to make themselves practically independent of the whole of the nickel people, and thereupon Le Nickel managed to get them to take a long contract at a comparatively low price to keep them out.

Q. To keep them from establishing nickel refineries of their own? A. Yes.

[*Robert Mond; Robert Mathias.*]

Q. Were they working with the Anglo-French Company? A. Yes; they are practically the same people.

Q. The chief difference between the two companies would appear to be that the Anglo-French Company is wholly English, and the Syndicate is the same concern with the addition of the Austrian, French and Italian armament concerns, with Krupp of Essen added? A. Yes, and Dillinger.

CHAIRMAN: The Anglo-French Company only produce for their own requirements? A. They supply the British government and the members of the Syndicate at the present time.

Q. There is no other combine, so-called, outside of this that you are aware of? A. No.

(Mr. Robert Mond): As the nickel trade has developed, the consumption of nickel outside of these people has increased. Nickel plating practically takes no nickel. The platers do not take 100 tons among the lot of them. The fat-hardening processes give a new use for nickel.

CHAIRMAN: Hydrogenating fat and oil? A. Yes.

Q. That is getting a big thing, is it not? A. It is not very big.

MR. YOUNG: What is the future for the trade? (Mr. Mathias): Two hundred tons of nickel are required for 1,000 tons of nickel salts and that goes a long way in a year. I do not know whether that is likely to be a very important consumption or not.

CHAIRMAN: It all counts? A. Yes. It may increase by another 200 tons.

Agitation in Canada Hurtful to Industry

Q. I do not think I have any more queries. We have taken up a lot of your time, but the information will be very useful to us? A. Of course, the whole agitation in Canada does a lot of harm to the industry; it hinders us getting capital.

MR. YOUNG: What form of agitation have you in mind? A. The whole agitation.

CHAIRMAN: I do not discover anything very recent in it. A. (Mr. Robert Mond): No; we have been up against it a long time.

(Mr. Mathias): It is very difficult when a body of shareholders comes and asks us "What do these newspaper reports mean? Are you going to be stopped refining in Wales? Have the Ontario Government taken any steps to close you down?" That is what they ask us, and the bankers and brokers ask us how it will affect us.

MR. YOUNG: Then you see how important it is that you should give this Commission as much information as you can possibly supply, because our object is to get at the real facts of the whole nickel situation in every department and aspect. A. (Mr. Robert Mond): At the present time we employ a capital of about £3,500,000 to carry on the business, and it is all found in England.

(Mr. Mathias): We tried to raise some capital in Canada and could not. Ontario gets a bad reputation here in the city. It is a very serious matter.

A. (Mr. Robert Mond): Now we want to increase again, and that will probably mean finding another half million pounds. And it is not only money for the works; there is the money required for dealing with the business when you have got it. It means bigger stocks and bigger everything else, more matte afloat and more matte across here.

Q. Do you mean the increase by adding the new unit? A. No; the future units.

(Mr. Mathias): We want to make the British Empire independent of the nickel supplies of other states. That is our object.

CHAIRMAN: I suppose you have ample ore reserves in your present properties? A. (Mr. Robert Mond): Yes. We have only known that we have had them during the last two years. One of our difficulties was that up to about two years ago we did not know where our future nickel was to come from.

(Mr. Mathias): People come and say, "Why do you not make more nickel, and why do you not increase your plant?" But we are very conservative people; we cannot go and spend a million pounds, and afterwards find we have no raw material. As a matter of fact we had no mines and we could not find any. We looked for ten or twenty years. That is a fact—I mean you know that. If there was any mine going we were only too pleased to get it.

MR. YOUNG: It must be very gratifying to you to have these established bodies of ore now proved? A. (Mr. Robert Mond): It is very gratifying. Then there is another thing one has to remember, that one has to be able practically to work on at least a 20-year basis.

(Mr. Mathias): If you want to write down your capital, £3,500,000, in ten years, you have to write down £350,000 a year, which is the profit we make.

Q. In the statement you are preparing, I understand you are not going to refer to depreciation? A. (Mr. Robert Mond): We will give you a figure marked down for depreciation, which you can put in or leave out as you think fit.

Q. In the form of percentage? A. Yes.

(Mr. Mathias): That has to be calculated.

(Mr. Robert Mond): All our staff in Canada are of opinion that we ought to write smelting off in ten years. When we started, the first innovation we made was to introduce the Bessemer process in regard to those ores. It had been tried on a small scale by Messrs. Vivian, but was no longer in operation, or being used by others.

[*Robert Mond: Robert Mathias.*]

Q. You were the very first to do that? A. Yes.

Q. You were pioneers there? A. We were pioneers. Then when we got the Bessemer process, the next improvement we made in the metallurgy was putting the slag into big settlers; we gradually increased their size, and finally got them to work.

(Mr. Mathias): I think you have that.

CHAIRMAN: We have it in the statements, or at any rate we have it in our own notes. We got that from Mr. Corless. We had long and most useful talks with him.

MR. YOUNG: We are very much obliged to you for the time you have given us. I do not know if anything further occurs to you? A. We have tried on several occasions to raise capital in Canada through the Canadian Bank of Commerce; we wanted to give the people in Ontario an opportunity of investing in our concern. We discussed with the bankers the question of making an issue, but we never could.

Q. We are busy subscribing for war loans now. A. This was before the war.

CHAIRMAN: That is curious, because an investment in your company sounds rather a taking proposition, does it not? A. Yes, but they want higher interest over there than they do here. We could raise money here at 5 or 7 per cent. at the time.

(Mr. Robert Mond): You want to raise large sums of money at 5 or 6 per cent. in order to pay interest on the ordinary capital. You have the American system of money, bonds and stocks. It has its advantages, and it has its disadvantages. It has one very great disadvantage, and that is this: in England a company is never allowed to buy its own shares.

MR. YOUNG: Nor with us either, legally. A. I do not know how it is with you, but in America a company can do all sorts of funny things with its stock.

The Question of Taxation

Q. A company with us cannot invest a dollar in its own shares without special legislative authority. Does anything else occur to you? A. (Mr. Mathias): What about taxation?

Q. That is coming to the front again, is it not? A. Do you know we have to pay £40,000 War Profit tax?

(Mr. Robert Mond): We have to pay a certain amount of War Profit tax before we become a munition works. It is one of the most complicated jobs you can imagine. The work is done at different times, over different periods and under different conditions.

(Mr. Mathias): And now they have a Canadian War tax too.

Q. Mr. Corless has given us a pretty elaborate memorandum on the subject of taxation, and Mr. J. M. Clark has done likewise. If there is anything which you want to add to these statements, which I suppose you have considered, we would be glad to receive it. A. What we have to pay here does not interest you over there.

Q. Well, it is interesting to us, you know. A. And the income tax is 5 shillings in the pound.

CHAIRMAN: We have to consider that. If you are paying so much in one country, you do not want to pay so much more in another country, so that it does come in.

MR. YOUNG: Can you tell us the tax you pay in England at the present time, and what you paid before the war? A. Yes.

MR. YOUNG: And if you desire to supplement in any way what we already have on the subject of taxation, we will be very glad to receive it.

CHAIRMAN: There are several memoranda relating to that.

MR. YOUNG: Of course the question of taxation has been much discussed between the Mond Company and the Government? A. We have these mines free of royalty.

Q. That has been very forcibly represented to the Government. A. If you give a freehold house you cannot come afterwards and say, "You must pay ground rent for it." Is not that so?

(Mr. Robert Mond): You are getting up against a peculiar difficulty there, and that is one which all countries have come up against. It is very foolish for a country to sell an inch of land freehold; it ought to give a lease, and it would maintain its rights and remain the ultimate landlord. If it does not, it gets itself into these difficulties later on. Take increment value and all that. If the Government simply granted land on a rational system of leasehold this increment value would never arise, because it could put up its rent; also, if improvements were wanted in towns, it would be perfectly possible for the Government to manage those things and not allow itself to be practically blackmailed by every landlord on the place, because that is what it comes to. You find out the difficulty in a closely settled country, but then it is too late because the process has been going on for a couple of thousand years. But when one has the chance to protect oneself for the future, I think one ought not to let it slip.

Following is an extract from a letter dated 3rd July, 1916, written by Mr. Robert Mond, of the Mond Nickel Company, to Mr. G. T. Holloway, Chairman of the Commission, bearing on a portion of Mr. Mond's evidence before the Commission:—

[*Robert Mond; Robert Mathias.*]

"As requested I am returning the report of the evidence given on the 27th April, which I have corrected, but find the part dealing with the Anglo-French Company and Steel Manufacturers' Nickel Syndicate does not appear quite clear, and should like in a few lines to give you the history of both companies.

"In 1900-1902, the Steel Manufacturers' Nickel Syndicate, which was composed of the principal armour plate firms in Europe, acquired the Anglo-French Nickel Co. This latter company had nickel refining works at Swansea.

"The Syndicate had at that time an option on a large number of nickel mining properties in New Caledonia which had been reported upon by several experts and mining engineers who had been sent out.

"Soon afterwards the Syndicate entered into a long time contract with the French Company (Société Anonyme Le Nickel), who were at that time the chief producers of nickel, for the total consumption of nickel of the various members of the Syndicate at a more or less fixed and favourable price. At the same time arrangements were made by the Anglo-French Company with the French Company under which the latter agreed to supply the former with raw material (nickel ore or matte) necessary for their refining works.

"In 1903-1904, when the Mond Nickel Company came into the market with their Canadian nickel, they found the greatest difficulty in marketing it amongst the armour-plate firms, especially in Great Britain, owing to the existence of the arrangement mentioned above. Eventually an understanding was arrived at between the Mond Nickel Company and the French Company under which the former arranged to supply Canadian nickel to some members of the Syndicate at the same price as the French Company supplied the members of the Syndicate under their long time contract.

"This, in short, is the arrangement which was made and which appears to be rather involved in the evidence."

Why Refining in Canada by Mond Process not Feasible

Memorandum No. IV by the Mond Nickel Company, Limited

I. *Climate*: The Mond process is one of extreme skill, requiring delicate differences in temperature. The constant temperatures and delicate differences would be matters of extreme difficulty and cost, if not impossible, in a country with a climate showing extreme variations of 100° to 150° Fahrenheit.

II. *Nature of Process*: The entire process is one requiring the very highest skill and training. For example, the gas, nickel carbonyl, is a deadly poison, and the entire volatilizing plant has to be gas-tight and continually searched for leaks. Neither the apparatus nor the workmen would be procurable in this country.

III. *Cost of Materials and Labour*: The raw materials, other than matte, are procurable in this country only at very much greater cost. Very little of the highly skilled labour would be procurable here, and such as would be, would be at much greater cost.

IV. *Freight*: Owing to the manufacture of copper sulphate (not copper) and of some quantity of nickel salt, the freight to market on the refined products would be considerably more than double the weight of the matte at present shipped. The freight to be paid would probably be not less than two and one-half times that paid at present, which is already very heavy.

V. *A Very Costly Plant to be Sacrificed*: The Mond Nickel Company in the best of faith and with reasonable assurances, has already expended many millions of dollars in Canada and in England, in establishing an industry which involves the annual expenditure in Canada alone of several millions of dollars, and which employs at its Canadian plants at present about 1,500 men. The company has operated for fifteen years already, and will continue to operate for a considerable number of years yet, before the capital already expended will be recovered, to say nothing of ordinary interest earnings and real profits on wasting assets.

If their reward is to be practically confiscation, how will prospective investment by British investors of any further capital in Canada be affected?

It is a practical certainty that with the handicaps imposed, only part of which are above outlined, the company will be compelled to build a smelting plant near their refinery for the smelting of ores from other countries, on which low ocean freights are procurable. As the nickel market is closely limited, the only result can be a loss to Canada.

VI. The ores from the mines are already crushed, sorted, roasted, smelted and converted into a matte of over 80 per cent. pure nickel and copper. This series of manufacturing processes is already more than is applied to many Canadian raw products, such as timber, grain, etc., and is the same as is applied to copper. Is there any sound economic reason why nickel should be discriminated against, or why an export duty should be imposed on unrefined nickel and not on unrefined copper?

[*Robert Mond; Mond Nickel Company.*]

VII. The Sudbury district shows many examples of failure to bring nickel mining, smelting and refining to commercial success. As examples, we would mention the plants erected by R. R. Gamey, The Dominion Mineral Company, The Dominion Nickel-Copper Company, The Hamilton Nickel Company, The Vivian Company, The Great Lakes Copper Company, and others. All of these proved to be failures. The Mond Nickel Company is to-day profitably working several of the mines of which some of the above companies made failures. Two of the failures were in fact by parties who are now making loud declamations in the press, calling upon the government to penalize exportation of nickel matte. The Mond Nickel Company has after nearly 30 years of careful experimenting in refining, and 15 years' experience in operation as well as development of a market, brought these properties to a profitable stage. Is it reasonable to expect this company to continue profitable operation where so many others failed, if the government legislates in such a way as to bring on them the accumulated effect of the numerous handicaps above pointed out?

(Sgd) C. V. CORLESS.

September 27th, 1915.

SECTION J

BRITISH AMERICA NICKEL CORPORATION, LIMITED

Evidence of Mr. J. E. McAllister, M.E., Manager British America Nickel Corporation, Limited

(Toronto, 23rd November, 1915.)

Origin of Company

CHAIRMAN: We shall be glad to receive information regarding the general arrangements that have been made as to the British America Nickel Corporation continuing or re-starting operations, and, shortly, anything you can tell us as regards the prospects of refining and the nature of the processes which you propose to use? A. This project was taken up originally by the late Dr. Pearson, and a Canadian, James H. Dunn, a banker in London, and E. R. Wood, in Toronto. This was over three years ago. They came to see me about it, and I discouraged them, for two reasons, and advised them to let it alone. The first of these reasons was that I didn't think they could refine at a profit. I didn't think they could economically make a refined product of this nickel, and then, when they did make it, I thought they would have difficulty in selling it, on account of the controlled condition of the market. Dr. Pearson's plan was to adopt the Hybinette process for refining nickel as practised at Kristianssands, Norway, which I didn't believe in, because it had been tried at Fredericktown, Mo., without success; but he said he would send an engineer over there, and have him report to us, and asked if it looked favourable enough to warrant further investigation, would I follow it; to which I agreed. So he sent an engineer over to Norway, and this man lived at Kristianssands for about two months, reporting both to Dr. Pearson and to me, every week. When I had received some of these reports I realized that there was more in the process than I had supposed, and by the time he had completed his investigation it looked very well worthy of being followed up, and I agreed to investigate it and went over. I cabled to England and had a man come to Norway who had been associated with the Mond Company in the starting of their enterprise here and throughout the entire development of it, and we investigated the process together. We spent considerable time in Norway, and concluded that it was all right. We estimated what the refining would cost when it was handled on a larger scale and with labour saving appliances, and on the basis of this investigation the syndicate which Dr. Pearson had formed purchased the right to use this process for all ore mined on the continent of North America.

Q. When you speak of the rights on the continent do you include the States? A. Yes, the continent of North America. All ore that is mined on this continent. For instance, you could not, under our agreement, ship ore from here to any other country, for instance, to South America, and use the process. It is for all ore that is mined on this continent.

Q. And could you use it on ore produced elsewhere, and brought to Canada or the States? A. Yes, it doesn't cover that. We could not protect ourselves in that way. From what we knew of the process, it was especially adapted to Canadian nickel ore, and the bulk of the world's supply was coming, and, we believed, would continue to come from this country. The next step following the purchase of this process was to acquire proved mines, and, under option, they bought the Dominion Nickel-Copper Company. Mr. J. R. Booth and Mr. M. J. O'Brien, I think, owned most of the stock, except a very small part that was held by others, and they purchased the entire property, including a short railroad they had, called "The Nickel Range Railroad," which connected one of their largest mines with the Canadian Northern. The purchase was made, I think, under six months' option, during which time we had the right to prospect the properties. The exploration work which was done on the Murray mine during this option opened up by diamond drill a very large body of ore suitable for this process. Subsequently the company was formed, the British America Nickel Corporation, which took over the Hybinette process and the mines.

MR. GIBSON: You have not a list of the mines, have you? A. I think so.

CHAIRMAN: It includes the bulk of those formerly owned by the Vivians?

MR. MCALLISTER: Well, you know, the Murray was Vivian's property.

Q. And there were a lot of little ones? A. Yes. I don't know that it takes those in. It takes in the Lake Superior property. The chief mines—they are in groups here. There is the Murray, the Elsie and the Lady Violet. Then, the Gertrude; the Whistle and Wild Cat; Victor, Blue Lake, and Falconbridge.

Q. Does that mean three groups? A. We group the Murray, Elsie, and Lady Violet; then the Gertrude; and then the Whistle and Wild Cat; that was the third group, and Victor and Blue Lake in a group; Falconbridge; and Nickel Lake, that is six.

MR. GIBSON: I suppose we could get a list by lot, concession and township? A. Yes, I think so. The property is very extensive. There are about 17,500 acres altogether. It isn't all mineral land, but we can give you particulars of all the lands.

CHAIRMAN: It would be convenient if we could have that. A. Shortly before war broke out, the syndicate was going to finance the company, but these plans were all interrupted on account of the general financial conditions caused by the war, so that the entire expenditure, so far, has been carried by the syndicate, and they are now making plans to do their financing and carry on the work.

Q. Then, your idea is based, I suppose, on the use of this process in conjunction with the special ore which you get in that district? A. Yes. Our ideas were based on the ore we got there, and what we know we can do with it by the methods of mining and smelting and refining which we will use.

Q. And your idea, of course, is to carry it right through from the refining to the sale of the nickel? A. Yes. We will make nickel of 98½ per cent. or better, and we will make copper of "Best Select" brand, such as is in use in this country, and we will also save what precious metals there are.

Q. Yes. That may be quite an important thing? A. The Hybinette process of refining, in regard to saving the precious metals, is identical with the electrolytic refining of copper, the precious metals being recovered in the mud; in tanks holding the electrolyte.

The Hybinette Process Described

Q. Could you give us any description of the process. A. The patent is described in the Dominion Government records, and there are diagrams there which show the unit plant. But it is something like this. (Rough sketch was drawn.) This represents a section of the outer tank holding the electrolyte, though, of course, in actual practice, instead of that tank being one unit, there are several, and these tanks are in rows the same as in copper electrolytic refining. Then at intervals, as closely as possible, canvas bags are inserted in those tanks, and the cathode plate is in that bag; the anode is in the outer tank; then the flow of the electrolyte is maintained from the cathode to the anode, by hydrostatic pressure, the level of the liquid in the canvas bag being higher than in the outside tank, and the electrolyte fed into this canvas bag overflows from the outer tank. The electrolyte which goes into the canvas bag is pure nickel sulphate solution, and this is a neutral solution. Then, by electrolysis the nickel is precipitated out from the solution, leaving it acid, but the hydrostatic pressure causes a constant flow from cathode to anode, and the acid solution dissolves the anode and regenerates itself from the copper and nickel of the anode. You are probably familiar with the work that is carried on in Sudbury now, where they make an 80 per cent. matte. That matte contains about 80 per cent. copper and nickel, and the balance is sulphur. In the Hybinette process this matte is roasted until the sulphur is brought down from 20 per cent. to about 5 per cent.; then the roasted matte is put through a cupola furnace, and these anode plates are cast. The Hybinette anode contains about 95 per cent. copper and nickel and 5 per cent. of sulphur. That anode then is dissolved by this acid solution which takes up the copper and nickel from the anode, and overflows from the tank back to what are called the cementation tanks. These cementation tanks are very large. They are made of reinforced concrete, and in them the copper is cemented out of the solution on waste anodes from the electrolytic vats, leaving the nickel in solution, and the pure nickel solution then goes back to the canvas bag.

Q. How about the iron? A. The iron does not interfere. It did interfere until they put in the basic Bessemer process. Up till about two years ago they were making in Norway a blast furnace matte, which they were concentrating in a Japanese hearth, similar to a blacksmith's forge, and these hearths were in a long line. A few shovelfuls of 40 per cent. matte, which came from the blast furnace, was shovelled into the blacksmith's forge and it was concentrated, the iron being slagged off. The blast furnace matte is a combination of copper, nickel and iron, with sulphur, and while they were working with these hearths they made about a 78 per cent. matte, carrying something over 2 per cent. iron, which they had to remove. Now, they have installed, as they have up here in Sudbury, basic converters. The chief advantage of these is that they can now Bessemerize a matte at almost any grade. In Norway, they Bessemerize copper-nickel matte of about 8 per cent. copper-nickel as it comes from the blast furnace. This Bessemerized matte now carries only about half of one per cent. of iron, or not more than three-quarters; they may bring it down to a half, and that does not interfere; but when it had 2 per cent. of iron they had to precipitate it out with a solution of nickel carbonate, throwing down the iron as carbonate, and that carbonate of iron was filtered off. The nickel carbonate solution was made by combining nickel sulphate with common salt, resulting in a small amount of waste product of sodium sulphate. This operation is done away with now.

Factors Governing Site for Refinery

Q. By the way, have you control over any future patents which Hybinette takes out on this continent? A. Yes, our agreement covers that. That, in brief, is a history of the process,

[*J. E McAllister.*]

and our connection with it. Now, we can put that in operation in any country where we can get electric power. It depends on the cost of power and supplies.

Q. You mean, whether you finish it at the mine or at some other centre? A. Well, the cheapest place for us to finish it would be at tidewater, just as the International Nickel Company does. Our supplies would be cheaper, particularly fuel. You see, we have got to use a lot of coal in the cementation, because that solution must be kept hot.

DR. MILLER: Is coal much cheaper in New Jersey than on the Niagara peninsula? A. I should say about one-third cheaper. They can generate electrical power there a good deal cheaper than you can buy it out west, and generate it from steam. You see they can lighter this coal right into the works. They are right on tidewater. And the same thing applies to most of their supplies.

Q. What coal is it that they would use? A. Either anthracite or bituminous. Then, apart from the electrical power, the next thing is the temperature of the buildings. The buildings are very extensive, covering a large area, and the temperature of the air, on account of the tanks, is quite an item. These solutions, in order to get good work, must be kept at a known temperature, and the operation of the process would be cheaper where that could be obtained with the least possible expenditure. For instance, it would cost less to operate it in a milder climate than Sudbury. At the same time, there are offsetting conditions in the fact that everything could be done up there under one head, under one management, and the anodes which were made from the bessemerized matte would just go from one department into the other. We have not finally decided where we will refine.

CHAIRMAN: I suppose there are a good many places on tidewater which could be selected, but as to Ontario? A. If we refine in Ontario, it will probably be either at Sudbury or at Thorold.

Q. Where you have got cheap current? A. Yes.

Q. Of course, you are lucky in having no by-products. A. There are no by-products. In refining at Niagara, the anodes would be made up at Sudbury, and there would be practically no gas to speak of at all, excepting the ordinary coal gas from the coal used, and such fuel as was used in melting up the cement copper into anodes.

Q. Would you do that yourselves, or would you send your copper to be refined by others? A. We would like to do it ourselves, I think, if we established a refinery here. I think there should be a field for the refining of copper produced in Canada.

Q. Yes, and then you would have control of the precious metals. A. Yes.

Q. Although I suppose, under any circumstances, they are all caught in the slime. A. Yes. I don't know if we would refine that. It would be a small quantity, and could be more economically handled by one of the small refineries such as those in New Jersey that make a specialty of this work.

Q. But you are in the position of being paid for it, which you would not be in any other form? A. No. It is in tangible form. It could be handled, but the amount of work in that kind of refining is very small.

DR. MILLER: They are starting now at Trail, under a bonus from the Government? A. Refining the copper?

Q. Yes, I think so. A. Everything they have made there is sulphate. What was the bonus?

Q. I don't know whether it was the bonus that was mentioned in the newspaper or not. A. There was a bonus mentioned that I heard of, two cents a pound.

Q. That is the only statement I saw. A. I think that is the only way we could establish refining in this country. All the copper produced in Canada at the present time, exclusive of the copper that is combined with nickel, would barely make an economical output for a copper refinery; that is, to compete with other refineries in the United States. The result would be that any copper producer could always get his copper refined more cheaply by these works in New Jersey than it could be done in Canada.

CHAIRMAN: But you think it would be advisable to put up an extra unit for treating the copper, in conjunction with your nickel plant? A. Yes. You see, it would simply be another wing to the building. We would have the management and the technical skill there, although it would pay us better to ship it over to New Jersey, and refine it there. But if we could get Canadian copper sufficient to make an output of the size that would permit of economical work, then it would be much better for us to refine the copper here and control and make the finished metal in this country.

Q. And the amount of sulphur in your anodes, how much? A. About 5 per cent. That varies. The only object of leaving that sulphur in is that if it was all taken out the oxides would be extremely difficult to melt, so enough sulphur is left there to make sufficiently fluid metal.

Q. And it is easier to run into anodes? A. Yes, it makes a smoother anode. Then, of course, a certain amount of sulphuric acid is always lost from the solution, because the cement copper is impure, and the nickel which is combined with that cement copper must be extracted. That is done in the copper process, by using "slow tanks" with insoluble anodes, and the nickel comes out as sulphate and is evaporated. This takes up the sulphuric acid from the mother solution.

[*J. E. McAllister.*]

Q. Suppose you left the 20 per cent. of sulphur in your anode? A. Oh, you would have too much. From 3 to 5 per cent. is best. If it could be worked with 1 per cent. it would be even better, but that would not be sufficient. Hybinette was using this process in Missouri.

DR. MILLER: Yes, but the lead bothered him there. A. Yes, there was lead, and it was a most complex ore.

New Caledonia Unable to Compete with Ontario

Q. You have referred to the fact that the bulk of the nickel is now coming from Canada. I would like to ask whether you think there is any danger of competition, for instance, from New Caledonia and other deposits? A. I don't see how the New Caledonia ore could be worked in competition with that of Sudbury. I think the nickel would cost too much. If basic deposits carrying other metals were to be found in the neighbourhood of New Caledonia, then they might be able to do it. Their cost of supplies would still be heavy, but the main expense is the refractory nature of the New Caledonia ore. Every particle of acid that it contains has to have a corresponding amount of base to make it fluid, and I don't see how they could compete unless basic ores which had enough values to carry themselves were to be discovered in the neighbourhood. Even then, their cost of supplies would be great, because they haven't got any coal convenient for the manufacture of coke for smelting. It may be that a chemical process will eventually be developed, but from known conditions now, I don't see how it could compete.

Q. Their smelting industry has started up again in recent years? A. Yes.

Q. About the deposits in Norway; they are much smaller there? A. They are limited in extent.

Q. And there is not much fear of competition from that source? A. No. The ore there is of a lower grade, considerably lower than at Sudbury. If we could do it without any expense or very little expense, it would be desirable to advance concentration in the blast furnace, but all it would do would be merely to shorten the time in the converter.

MR. GIBSON: How does the rate of wages compare in Norway with that in Canada? A. I don't think there would be much difference. The rate of wages is lower, but the efficiency is not as good. It might be slightly in favour of Norway, on the aggregate, of from 5 to 10 per cent.

Q. Are your figures based on the Norwegian rates of wages? A. No, our figures are based on what we pay up here.

MR. YOUNG: Would you mind amplifying for me, as a layman, just a little, your earlier statement that your process is peculiarly adapted to Canada? Just in what respect? A. Well, to this ore. Not to this ore, but to ore of this nature.

MR. GIBSON: You spoke of the necessity of maintaining a definite temperature? A. Yes.

Q. Would that be more difficult to do in Sudbury than in Norway? A. Oh, yes. Kristianssands is on the sea, and there you get a much more even climate. Kristianssands is something like Constable Hook.

DR. MILLER: It gets pretty cold in New York sometimes? A. Yes. I don't think you get the extremes in Kristianssands you do in New York. The snow doesn't lie nearly the length of time.

MR. GIBSON: Would this process you have been describing to us be more or less favourable according to the tenor of the ore? A. I don't think it makes any difference. It would be more favourable on rich ore simply because you would have to mine and smelt fewer tons of ore up to 80 per cent. matte. The refining process only takes care of any metal from the 80 per cent. product. In so far as the refining process is concerned, it doesn't matter whether you are starting with a 2 per cent. or a 4 per cent. or a 10 per cent. ore, but it materially reduces the total cost. The practice in this country and in the United States is to figure costs on the ton of ore up to and including the blast furnace, and from then on, on pounds of metal, because that is the last place the ore is handled, in going into the blast furnace; and the blast furnace capacity is always rated by the number of tons of ore it will handle in twenty-four hours; the number of tons it will smelt. The converter capacity is rated by the pounds of metal it will turn out as 80 per cent. matte, or blister copper.

CHAIRMAN: If it prove practicable to smelt green ore entirely, what effect would that have on the sulphur problem in Sudbury? A. Very material. Of course, you would get just as much sulphur, but in coming from a high stack it would spread, and wouldn't have the same effect on vegetation; not anything like the same effect it has now. It is the roasting that does the harm; the tremendous volume of smoke close to the ground.

Q. There would be the possibility of recovering the sulphur? A. Yes, it could be recovered, but I don't know whether it would be commercially possible. Where they do recover it is in localities where it is saleable. In the south, for instance, the fertilizer companies use it, but up at Sudbury the sulphuric acid would be difficult and expensive to transport; and you have that to contend with. It is purely a commercial question. They could employ a chamber process. They could save the sulphuric acid, and, I should think, it would be fairly pure too, because there is no arsenic in it.

[*J. E McAllister.*]

Q. That is where the chemists should get busy? A. Yes. If coke were made up there, for instance, instead of being imported, quite a lot of the acid could be used, even in the manufacture of ammonium sulphate as a by-product, and from the coke they could have the gas which could be used in the town of Sudbury, and also for power. These things are a question of whether it is wise to put the capital into them.

Q. Isn't there a duty on coke or some inducement for slack coal to come into this country? A. I don't know. They could bring all the coal in there by lake and stack enough to run them for four or five months, all winter, and keep on making coke all the year round.

MR. GIBSON: They make coke, of course, at Sault Ste. Marie? A. Yes, they are making coke at the Sault.

CHAIRMAN: And very good coke. A. Yes. They, of course, control their own mines in Pennsylvania and Virginia.

Q. After this war is over, what do you think will be the demand for nickel? A. I don't know. I can only tell you what those who are in a good deal better position than I, say. They say the demand will be much greater. I don't see why it should not be. I don't know what could replace nickel except vanadium, but there is not enough of it.

CHAIRMAN: What is the relative amount of nickel used for steel and for other uses? Have you any idea? A. No, but I do know that in some of the steels which are being made in England now, they are using greater percentages of nickel than in the past. They have got it as high, for some, as 30 per cent., and it has always been supposed that the best combination, the best alloy, was about 3½ per cent.

Q. That is what they use for automobile parts and bridges, and so on? A. Yes. The Quebec bridge is now being made of it, because the tensile strength is obtained with a much lighter section. I have no definite idea what the consumption of nickel will be when we reach normal times again. It would seem that there must be a great revival of industry.

A Narrow But Expanding Market

Q. It seems as if there is a growing necessity for nickel? A. Yes, I think so. Its uses are narrow, and yet, at the same time, it is absolutely necessary. I don't know what can replace it.

MR. GIBSON: Are you speaking of its use for making steel alloys when you say it is not replaceable? A. Yes, and after all, that is the great fundamental use it will have to be put to, it seems to me. Its uses apart from that will be comparatively small.

CHAIRMAN: I have heard it stated that over 60 per cent., apart from war requirements, is used for steel? A. Yes I don't think war requirements will bring out the main feature of it. Of course, a good deal of attention has been given to that, because it is absolutely indispensable in armaments. They cannot get along without nickel for armour plate for battleships, and also they must have extremely high tensile strength for ordnance. In other words, it is a necessity for war purposes. For other purposes it is a question of commercial economy.

DR. MILLER: There are quotations of nickel in the technical journals, I mean in normal times; they would seem to me to be higher than what it is sold at? A. It is very difficult to tell what the normal price of nickel is, because it has never been dealt with on the open market like any other commodity, such as iron, steel or copper, or lead, or spelter. There have been only two or three purveyors of nickel in the world, and the entire business of selling has been in the hands of the Germans.

Q. The Germans really controlled the French companies, didn't they? A. Yes, but I believe those figures as given by the Metallgesellchaft, published in the Dominion Government statistics, are, in the main, correct. I think that an average price of about 35 cents to 36 cents a pound has been realized for the past ten years. Some nickel has been sold much higher, of course. Now, it is abnormal.

MR. GIBSON: Has there been an increase in the price owing to the war? A. Yes; Germany is paying £750 sterling a metric ton. They are paying in Great Britain from £190 to £200 sterling a ton.

Q. I see it is quoted in *The New York Engineering and Mining Journal* at 45 to 50 cents a pound? A. That does not mean anything. Now, copper is different. There are so many producers of copper. They have got to have a medium of settling, and in this country they usually settle on the quotation of the *Engineering and Mining Journal;* but nickel is entirely different. There is no means of rating it.

DR. MILLER: I think it has been stated by some companies that they have not increased their price to their old customers? A. I don't think they could, because they are under contract; and not only that, but some of those contracts have a clause in them providing that if the price became open and fell below the rates in the contract, this price would have to be met.

Current Prices of Nickel

CHAIRMAN: I have heard that the Russians have paid a big price for some of their nickel; is that correct? A. I don't think the Russians would pay any more than Britain, but in Germany they are paying enormous prices.

[*J. E McAllister.*]

MR. YOUNG: What is it we hear, 49 cents a pound to the Russians? A. Well, 50 cents a pound would be $1,000 a ton; £200 sterling is about right, I should say. The British Government, or rather their agents, have paid as high as £210 sterling within the last six months for quantities up to two thousand tons of refined nickel, and I think that just recently the price varied from £195 to £210 sterling per long ton. But these prices are abnormal; they won't last. It would be more interesting to see what an open market for nickel would do. There is no question in my mind that a drop in price would enormously increase the consumption.

MR. GIBSON: The practice now is to sell on contract for a number of years? A. Yes.

Q. How long a term is customary? A. Five years; ten years, sometimes.

Q. At a fixed price? A. Yes. Copper, on the other hand, is always open. The producer of copper never knows what he is going to get ultimately, because the price isn't finally settled until perhaps sixty to ninety days after it has left his hands.

DR. MILLER: In connection with these alloys; you have spoken of 30 per cent. nickel in some of them. What would be their special uses? A. For ordnance. That is for war purposes altogether. I cannot tell you what goes into them, but the British Admiralty has specified that, I think, for some of its steel, some of its alloys. I think that a change has come about during the war in this respect, that the Government, perhaps not in name, but through agents, has taken a much more active part in regard to the products that go into the finished materials.

Q. Then it would look as if they would want to have the nickel refined in the Empire, wouldn't it? A. Yes.

CHAIRMAN: Of course, that is where the economic doubt you were speaking of comes in? A. Yes. If the British Government, or, rather, the Government of the Empire, could have been able to lay its hands on the finished nickel from two years before the breaking out of this war, we might have seen a different state of affairs. And the same thing applies to everything; the making of phosphates, for instance, and certainly to copper, and likewise to our iron industries, such as they are.

MR. GIBSON: I suppose you have an estimate of your company's ore reserves? A. Yes, I can tell you what those are now. Of workable ore, the company has about 11,000,000 tons blocked out to date.

Q. That is known ore, I suppose? A. Yes.

Q. Then there is a probability of other or larger bodies? A. Yes.

Q. Did you bring the schedule of queries which we sent you? A. Yes, I did I think there are very few things there that apply to our operations excepting what we have dealt with. We are in the preliminary stage. The name of the company is the British America Nickel Corporation, Limited.

MR. YOUNG: Incorporated under the Dominion Companies Act? A. Yes.

MR. GIBSON: What is the nominal capital? A. It has $20,000,000 of common stock, and it has $10,000,000 of debenture stock. It has also $3,000,000 of bonds outstanding. Regarding its assets and capital invested in Ontario, I doubt whether we could classify the assets now, because the project is in the development stage, the money that has been spent has been for the purchase and development of the property and organization. "Charges for assessment," hardly applies to us, because we have not been operating yet. The same applies to "aggregate pay roll," and the cost sheets we haven't got yet. Our costs are estimated, and with regard to refining nickel in Ontario, I think we have gone fully into that. The operation of The Mining Tax Act I haven't had an opportunity of looking into. You see, we have not been operating or making any output. "Information regarding the use and demand for nickel." I think we have dealt with that. The mining costs we have not got.

Evidence of Mr. James H. Dunn, President, Mr. E. P. Mathewson, General Manager, and Mr. W. A. Carlyle, Director of the British America Nickel Corporation, Limited

(Toronto, 3rd November, 1916)

CHAIRMAN: We have met to-day, gentlemen, to get any information we can from you on the same lines as that which we have received from the Canadian Copper Company and the Mond Company, and also in Norway. I had the pleasure of seeing Admiral Borresen, and he told me that we should get further information here, either from you, Mr. Dunn, or Mr. Carlyle, or Mr. Hybinette.

MR. DUNN: Yes, that is about this company; but I hope you got all the information you wanted from Mr. Hybinette's company.

CHAIRMAN: Not about the process. A. I don't suppose they would show you the process.

Q. Yes, they did. They gave me as much information as I was able to assimilate, but they told me the best plan would be to ask Mr. Hybinette or Mr. Carlyle to give us additional data. A. You and Mr. Hybinette must have crossed.

[*J E. McAllister; J. H. Dunn; E P. Mathewson; W A. Carlyle.*]

Q. Yes, he was here when I came, but I didn't know he was leaving. A. Mr. Hybinette was not very well, and decided to go home and return after Christmas.

Q. Well, could you give us some information as to the future working of the company and what your proposals are? A. I think it best for you to ask the questions and I will try to answer them.

Q. I understand that the company has made some arrangement with the British government. A. Yes. This arrangement I would much prefer you learned from the British government. I don't know that they would want me to discuss the arrangements. I think by enquiring through the Colonial Office you would get the required information.

Q. But to-day we are anxious to obtain two classes of information, one which you would like to give us for publication, and the other such as you could give us for our own private use, because, although we are going to take it all down, it will be submitted to you before we publish it. Of course, we have no wish or idea of publishing anything which would in any way help competitors, or anything of that kind, but there is a great public interest in new companies being formed, and especially in one which is going to be entirely Canadian and operate wholly in Ontario. A. And refining everything in Canada.

Q. So that we would like to have something in the nature of a statement as to what is being done? A. Our position is, we have acquired the various mines known as the Booth properties which altogether have proved up by diamond drilling approximately twelve million tons of nickel ore; these properties being the Murray mine, on which we have proved up by some sixty-three diamond drill holes, approximately eight and a half million tons of nickel ore. That is the first property we propose to work. We have sunk a shaft there about 750 feet, and near it we will erect our smelters, smelt our ore to an 80 per cent. matte, and refine that matte somewhere else in Canada; we are not yet sure where, but not likely at Sudbury for two or three reasons, the most important of which is, we have not got the power available there at low prices. In fact, we haven't got it available at any price now. We will smelt approximately one thousand tons of ore a day to begin with, and that will make approximately six thousand tons of nickel per annum.

Q. Of matte? A. Of nickel: approximately six thousand tons of nickel.

MR. YOUNG: Using the Hybinette process only? A. Using the Hybinette process only.

CHAIRMAN: There are certain particulars in this prospectus issued by the Canadian Nickel Corporation. I suppose they can be taken as reasonably up-to-date, can't they? A. Well, I really don't know anything about this at all.

Q. That was the old company? A. I had nothing to do with the direction of the company in those days. I don't know anything about this. I could not vouch for it being correct, nor could I say it is not correct.

Q. Is there any object in regarding this as correct? A. Well, you see, it was not issued by this company; by whom it was issued I don't know. My activities in the concern really began in a serious way after Dr. Pearson's death. I had advanced considerable money for the enterprise, but had not anything to do with its practical affairs until after his death.

Formation of the Company

MR. YOUNG: What is the correct name of your company? A. British America Nickel Corporation, Limited.

Q. Then, I understand that the O'Brien interests were really merged in the concern, which they called the Dominion Nickel Copper Company? A. I don't know what the name of the Booth company was, but we took over all the mines they had. I would just say this, then. When we bought them, or when Dr. Pearson bought them, the chief mine they had developed was the Whistle. They had done certain work on the Murray, but it was of secondary importance. They acquired the Murray from the Vivians', and certain properties from the Lake Superior Corporation known as the Gertrude, Elsie and Blue Lake. Dr. Pearson's investigations led him to believe the Murray was the most important property, and he had it very completely drilled. It proved to be a large and valuable mine, so our efforts at the present time are concentrated on this mine, which at one thousand tons a day would last for twenty-five years.

CHAIRMAN: Your headquarters for the Murray will be somewhere in the vicinity of that mine? A. Yes.

MR. YOUNG: Then a concern appears in the transaction, the Pacific Securities, as taking an option. Do you know anything of that? A. What I know I have learned from Mr. Lash. I think he can explain that to you.

Q. What is the capital stock of your company? A. Twenty million dollars.

Q. How much of that has been issued? A. It has all been issued.

Q. Is that in payment of the property, largely? A. That was all done in Dr. Pearson's time, and when I came I found that considerable of that stock had been paid away to Booth in payment of the properties and to O'Brien, his associate, and to the Norwegians for their process, and to various other people.

Q. Well, then, how much of that is preferred? A. None is preferred. It is all ordinary.

Q. And then what will your bonded indebtedness be? A. The bonds at the present time consist of a six million dollar issue. The debenture stock or second bond consists of a ten

million dollar issue; $3,000,000 of debenture stock was sold at par, and $500,000 at 97 per cent. Three and one-half million of that is outstanding. When the investment of the company is complete, we will have an investment of about ten and one-half million dollars of these bonds out, and four and a half of debenture stock, or we will have more debenture stock and fewer bonds.

Q. And I suppose the original proprietors must be holding some of those bonds? A. Yes. I am a very large holder of debenture stock.

Q. That is you, personally? A. Yes, which I acquired from Dr. Pearson or his estate.

Q. Then, as to the holdings of the company. I see that Mr. McAllister here was examined and he gave a statement, and I suppose that would be correct? A. Well, if I saw it I would know.

Q. He says the chief mines are in groups. There is the Murray, the Elsie, the Lady Violet, and then the Gertrude, Whistle, Wild Cat, Victor, Blue Lake and Falconbridge? A. Yes.

Q. Does that mean three groups? A. Yes.

Q. Do you know of any others that you have, or is that a complete list? A. I think we have some other options, but I don't know what the names of the properties are. Our vice-president is an old associate of mine, Mr. Frater Taylor, president of the Algoma Steel Company. We have an option on certain properties he brought to our attention, and if we do anything with these properties I will let you know.

Q. Then I can get the details and the whole particulars of organization, liabilities at commencement and out-standing contracts from Mr. Lash? A. Yes; and our secretary, Mr. Muirhead, who keeps the records, will be able to give you all that.

Buying the Hybinette Process

Q. Then, I think some of my colleagues are very much interested in this arrangement with the Norwegian company. We would like to have as much information in regard to that as you feel disposed to give us. A. In a general way the Norwegian position is this: they were interested with Dr. Pearson in the early days. He bought their process, and paid them partly in cash and partly in shares of the company. The British America Nickel Corporation, Limited, own the Hybinette process for North America. Not only for Canada, but for the United States and I think down to Panama, in case any nickel should be discovered down there.

Q. Did you ascertain at that stage where the British government was getting its nickel? A. I don't know, but I suppose they were buying their nickel in the open market, and I should think it was largely International nickel.

Q. Why do you think it was International nickel, because the impression in my mind is that they were taking a lot of that French nickel that came from New Caledonia and was refined by the French Nickel Company? A. Well, I remember a statement made by Sir Alfred Mond in the press not a great while ago in which he complained that it was with the greatest difficulty that he could get the British government to use his nickel.

Q. Yes, we are familiar with that statement, but I think the competition he was complaining of there proceeded from the French Nickel Company rather than the International. A. From New Caledonia?

Q. Yes. I would like to know if you could ascertain without too much trouble what was the chief source of supply of the British government, and when I say the British government I would like you to include as well the big armament manufacturers who were supplying the British government, because the British government was buying only the finished products from the steel and armament makers. A. I will try to get you this information. The Norwegian nickel went to Germany before the war, and after the war began that was changed in a large measure.

Q. What time in 1914 did you go to Norway? A. I made several visits in 1915, but I don't remember just what the dates were.

Q. Would they be all in the year 1914? A. No, I was there in 1915, and Mr. Hybinette also came to London.

Q. And at that time Dr. Pearson, or some of his assigns, had made their arrangement for the process in this country? A. Long before that time.

Q Now, when we were in England we got very definite assurances that a good deal of nickel was going from Norway to Germany. A. I would rather you got this information from the British government.

Q. I understood that they were making then at the rate of nine hundred tons a year? A. That is not correct. I think they did build up their smelting and refining capacity to about 1,800 tons, but they did not have the ore available to smelt.

Q. Twelve, they told me. A. Well, they went on adding to it afterwards. I think they assured Mr. Carlyle that they had a capacity of 1,800 tons a year.

Q. Are you at liberty to tell us where it did go? A. I understand what they made went largely to Germany, but some was used in Norway.

Q. That is, local production was stimulated to the extent of their capacity? A. The output was decreased, and the home consumption stimulated after the war began. The British government is interested in the British America Nickel Corporation, Limited, but how and

[*J. H. Dunn; E. P. Mathewson; W. A. Carlyle.*]

to what extent I think you should learn through the Colonial Office. In reference to the various wild statements that have appeared in the press from time to time, I might say that neither Mr. Carlyle, nor Mr. Mathewson or myself has talked to the press or made any statements. We are going on with the work and saying as little as possible, but we are glad to give this Commission full information except about the Government interest, which we think you should get through the Colonial Office.

Reducing Norwegian Nickel Exports to Germany

Q. As far as our anxiety is concerned, it is not based on newspaper statements, but we had a very direct and positive statement that last spring a good deal of nickel was going direct from Norway to Germany. Our Ontario people are naturally much interested in that, and we would like to ascertain the facts as fully as they could be given without regard to newspaper comments. A. Well, you can get from the British government in exact figures every ton that goes to Germany, because they have men there and know exactly what goes. The British government have their own men in Norway, and they know every ton that is made and shipped, so you can get your information from them, and then it will be exact.

Q. Well, have you any idea of the receipts of Germany from Norway for this present year? A. No, I have not. The information does not come to me. If I was in England I would probably know what it was, but I don't know at all.

MR. CARLYLE: It was impossible to stop the total production without, if I may say it, imperilling the neutrality of Sweden and Norway. There was a certain quantity contracted for which could not be prevented, but we got that reduced to a minimum.

MR. DUNN: Prior to the war the Norwegian company sold all its nickel to Germany. They made nickel, and had to market it, and sold it through a German firm: they hall-marked the product and made it known, because it was a new product.

Q. Well, Mr. Carlyle, I think we are quite assured that all precautions were taken by the British government to reduce the output to Germany to as low as possible.

MR. CARLYLE: Yes, absolutely.

MR. DUNN: The fact was, Germany wanted nickel badly and increased the price. They would say, "If you will increase your tonnage fifty tons a month, we will increase our price not only for the new production but for the old"; so the Norwegians were working as hard as they could in the mines and the smelters and getting the largest possible production, until by now they would have had a production of two thousand tons if they had the ore.

Q. Well, at that stage the Norwegian company that was operating at Kristianssands had a substantial interest in the British America Company, had they not? A. No, the company had not. A number of Norwegian individuals, including Mr. Hybinette, had.

Q. The company was not a shareholder in your company? A. To deal with the situation as it then was; the process belonged to a group of Norwegians who had sold the Norwegian rights to the Kristianssands Company known as K.N.R., and it was with them that Dr. Pearson dealt, and the stock that was issued was issued to them as a group.

Q. But at the present time is the company a shareholder, *qua* the company, I mean? A. I am afraid I don't know. I think they have an interest as a company, but the Norwegian interest in British America Nickel Corporation is chiefly held by various individuals over there.

Q. Now, we have ascertained, through a reliable source, that as a result of some of these efforts a long time contract had been made between the British government and the Norwegian company for the supply to the British government of a part of the nickel. When we were in England I didn't quite confirm that, and I would like to know how that was? A. Well, that again is a matter I think you could get through the Colonial Office. If we have any information about that it is incidental; it is not our business, you see, because our company has no interest in the Norwegian company.

CHAIRMAN: But the Colonial Office would have no information as to shareholding by the Norwegian company, or by Norwegians as individuals? A. I believe the British government has complete information.

Q. Well, I mean they would not be the people to approach on the matter?

British Government in Control of Company

MR. YOUNG: We can get that here, because under our law they have to file a list of shareholders. If there is any further information Mr. Carlyle or Mr. Mathewson could give us we should be glad to receive it. A. I think I may tell you one thing without any breach of confidence at all. $14,500,000 of the twenty million of common stock of this company is in the name of a British subject resident in London, and is, therefore, within control of the British government. Alan Anderson is the holder. You can find this out by the records here. The balance of the stock is all in the hands of people in Canada, with the exception of about $1,000,000 held in Norway.

Q. Wouldn't it be a very good thing to go to my friend, Mr. Lash, and ask for anything that my curiosity might suggest? A. Anything that does not give you any information that I think you ought to get from the British government itself, certainly.

[*J. H. Dunn; E. P. Mathewson; W. A. Carlyle.*]

Q. What the Commission specially invite is your co-operation with us that we might deal with all the nickel companies after obtaining a complete knowledge of the facts. A. I would just answer you right away; my wish and the wish of Mr. Mathewson and Mr. Carlyle is to deal openly with you and to tell you everything, and to ask you to help us in any way you can. We are here to mine nickel and to smelt it in Canada, and build up an industry so that it will be a creditable industry, and that is the only object we have.

Q. Yes; and, of course, we are very much interested, as you may realize, in the prospect of the company refining here in Ontario in a manner that has been approved of by these experts? A. Has been approved of by the experts of the British government.

Q. I understand that Mr. Carlyle, representing the British government in Canada, has made a careful inspection of the Norwegian works? A. Yes.

CHAIRMAN: Could we put down a word in the evidence saying what your position is respecting the British government over here, Mr. Carlyle?

MR. CARLYLE: In the first place, I was commissioned by the British government to proceed to Norway to examine the mines, smelters and refinery of the Norwegian Nickel Company in order to ascertain the producing capacity of this enterprise, and whether the refining process was or was not technically and commercially successful.

Q. That would be in 1914? A. No, in 1915.

MR. YOUNG: I think you have given us a letter showing the results. A. Yes, I have given in a few words in that letter my opinion of the process.[1]

MR. DUNN: Yes, we were so satisfied with the proved commercial success of the Hybinette process that we were rather of the opinion that it ought to be made compulsory to use it until you found a better in this Province. We thought that no other ought to be permitted.

MR. CARLYLE: I am now in Canada acting as one of the directors of the British America Nickel Corporation, and on behalf of the British government.

Q. Well, if they are really holders of $14,500,000 of capital stock out of a total issue of twenty millions, why, of course, they have control. A. The British government have absolute control.

Q. So that you are representing the controlling interest? A. Yes.

Q. Do the bonds carry bonus stock?

MR. DUNN: Well, they are not being sold. When the thing was organized the people who agreed to buy the bonds bought Dr. Pearson's stock, and as the company agreed to buy the bonds and bought the stock, when I took hold of it I could not get it back; but the part I did get back is very largely included in this $14,500,000 now in the name of Alan Anderson.

Q. When do you hope to get into actual operation?

Company's Plans and Prospects

MR. CARLYLE: Mr. E. P. Mathewson has just arrived to assume the duties of general manager, and has begun to make his organization, so that when his staff is assembled the designing of the plants may begin forthwith. We shall begin construction work early next spring, and in the meanwhile mining work is now in progress.

CHAIRMAN: And the refining plant will be a unit to produce at the rate of six thousand tons of metallic nickel? A. The first unit we propose to build will have a capacity of five thousand tons of refined nickel per annum.

Q. And when do you think that will be? A. We hope to be ready by the end of next year. These abnormal times are making it very difficult to get machinery, men and building material.

Q. I suppose we are at liberty to state that you have arranged with the British government to take a substantial part of your output?

MR. DUNN: Oh, yes, you are at liberty to state that they will take much the major portion of our output. In fact, they are our market.

Q. And naturally the balance will come into competition with the nickel produced by other companies? A. Yes, if there is a balance.

Q. It is considered desirable to encourage development of other properties, and as you know there are many small producers who could perhaps produce a low-grade matte, and as you also know, the Mond Nickel Company at present purchase some ore. Would you be willing to purchase ore from small producers? A. We would be glad to consider with this Commission some comprehensive plan of dealing with such ores and such matte. We would be glad to study with the government or this Commission the question of enlarging our capacity so as to take care of that situation.

MR. YOUNG: On reasonable terms to be arranged? A. Yes.

CHAIRMAN: That would be on the ordinary schedule based on assay values and quantities on a sliding scale? A. Well, we would not be prepared at the present time to provide the extra money to so enlarge our smelters and refineries as to hold ourselves out to the

[1] See page 131.

[J. H. Dunn; E. P. Mathewson; W. A. Carlyle.]

country as customs smelters and refiners. We have not got enough capital for that, but we would be very glad to consider with the Ontario government the question of getting from them such additional capital as would enable us to do customs smelting and refining.

Q. Then there might be ore suitable to smelt with your ore; that you would be glad of course, to buy? A. I think we do not need other ore for fluxing purposes.

Q. That is the position with the Mond, but on the other hand they are very glad of the ore that the Alexo produces, because it is a comparatively small amount and fits in very well with theirs. It pays them and also the Alexo, which has not been big enough to put up its own smelter. A. We would be very glad to discuss with you that situation. Our company will smelt and refine in Canada, and by a method that does not call for the importation of acids, or other chemicals from outside which would take Canadian money out, but will use strictly Canadian resources. It will, therefore, be an absolutely homogeneous method. Standing in that unique position, with a proposition which is actually Canadian, we are more Canadian and more Ontario than anybody else, and we would be glad to put our process at the disposition of the Ontario government on fair terms to so enlarge our plant as to be able to do custom refining.

Q. I understand that practically the only chemical you use is sulphuric acid, and that you have no trouble with the effluents?

MR. DUNN: Mr. Carlyle will tell you more about that.

Q. I would like to talk with you further about that, Mr. Carlyle. A. Well, I shall be in this country long enough to discuss that problem, and I would be delighted to take up that feature of the enterprise.

MR. YOUNG: Then you will give Mr. Lash instructions to give us details as to contracts that will facilitate us getting the information? A. Yes.

CHAIRMAN: There is one other question. Were you thinking of making nickel salts and copper salts and oxide? A. No, only the two metals. We make merchantable copper and nickel, and we save and refine all the precious metals. Our process saves the precious metals, and I think the Mond process does so too, but I believe the other process only saves such precious metals as are in the copper, in the refining of which they are obtained, but the precious metals that remain in the nickel are not saved. We save them, and we consider it a very important point, as the precious metal output of that particular district is sold all over the world without return as nickel or as an ingredient of nickel.

Q. There is one thing I am very much interested in: that is, in the calculations the precious metals throughout the reserves that belong to this company are estimated at a dollar per ton of ore. Is that somewhere near?

MR. CARLYLE: That is about the amount on which we are basing our figures, and I think it will be about that.

Q. MR. YOUNG: Would you have any objection to government control of your output as to its destination? A. I think it is controlled now.

CHAIRMAN: I expect you would rather welcome it? A. If it means that it gives us an opportunity of getting the usual normal price we haven't the slightest objection. As you say, I think we would welcome it.

MR. YOUNG: Well, in some quarters there has been a strong sentiment that nickel, because of its peculiar value for certain purposes, should be controlled? A. So long as we are not put in a wrong position with our competitors, we would welcome it. I think if you will apply through the Colonial Office to the Board of Trade, you will find that the stoppage of nickel from Norway to Germany is very substantial, and entirely to the government's satisfaction.

NOTE—The understanding is that Messrs. Blake, Lash & Cassels will give the Commission all the information regarding the Canadian Nickel Corporation and the British America Company and other companies that are connected with the acquisition of the property now held by the British America Company, together with inspection of the contracts and agreements which they may have and which are of importance to the Commission, subject always to what they think should be given by the British Government itself.

MR. YOUNG: Notwithstanding anything that may appear in the translation of these circulars to the Norwegian public, no one in the British America Company has any interest of any sort in the properties there, or will be connected in any way with their actual operation? A. That is correct.

Q. And any interest Norway has is as shareholders of this company? A. Yes.

CHAIRMAN: Have you considered as a business proposition, any allied or subsidiary industries?

MR. CARLYLE: Not yet, but as I stated the other day we think this is only the beginning of a large enterprise in this country.

Q. What would be the lines of that? A. Well, take the copper industry, crude copper refining, and so on. That may grow into quite a big thing, much bigger than it is at the present time.

[*J. H. Dunn; E. P. Mathewson; W. A. Carlyle.*]

Q. And any chemical industries at all within reasonable possibilities? A. We have not thought of any chemical industries.

Q. As regards the recovery of sulphur, partly to avoid the nuisance and partly for the sake of making money, what do you think of the idea? A. I think that within a very short time we will be making sulphuric acid where the refinery is located. We will be making sulphuric acid, and that is the basis of all these chemical industries.

MR. YOUNG: Is there an attractive market here for that? A. There is some market now, and there will be a great deal larger one in the near future. There are many things going to necessitate the greater use of sulphuric acid. The demand for sulphuric acid throughout the world is becoming enormous. In Spain we have been shipping a million and three-quarter tons of ore, fifty per cent. sulphur, and we could have sold double that amount if we could have delivered it.

MR. MATHEWSON: Where I have come from we put up a sulphuric acid plant to make one hundred tons a day and we thought we were away above the market requirements; we enlarged that within six months, and it is turning out 140 tons a day now and is not large enough yet. All the acid we are making is chamber acid. The concentrated acid is used only for comparatively few industries, and nearly all the acid, or a large proportion, is made as a by-product.

Letter from Mr. William A. Carlyle, M.E., respecting Hybinette Refining Process

In the following letter, dated 29th September, 1916, addressed to the Commission by Mr. William A. Carlyle, M.E., formerly Provincial Mineralogist for British Columbia, and for many years manager of the Rio Tinto copper mines, Spain, gives his opinion of the Hybinette electrolytic method of refining nickel-copper matte:—

"In 1915, having been commissioned to investigate the productive capacity of the Nickel Refinery at Kristianssands, Norway, I made two visits to that plant at an interval of six months. The Norwegian Company operating it own several nickel mines in that country and work two smelting plants, equipped with basic converters, producing matte containing about 80 per cent. nickel and copper, a matte essentially the same as that made at Sudbury.

"This matte was sent to the refinery for the extraction of the nickel, copper and precious metals, and at the time of my first inspection the plant was producing monthly over 100 tons of refined nickel, which production was in the process of being much increased. The method of refining there used is the Hybinette Electrolytic Process, and from my investigations I learned that this process was in every way being carried on very successfully, both as to the purity of the refined products and the costs of refining.

"Only a small amount of chemicals have to be procured for the starting up of the refinery, and thereafter practically none, almost the only requirements being then electric power, coal and some coke. No trouble is occasioned locally by emission of obnoxious gases or foul liquors, and there is nothing to prevent this process being successfully used in Canada for the cheap refining of nickel-copper matte."

SECTION K

NICKEL IN NEW CALEDONIA

Evidence of Mr. G. M. Colvocoresses, General Manager Consolidated Arizona Smelting Company, Humboldt, Arizona

[NOTE.—Mr. T. F. Sutherland, Chief Inspector of Mines for Ontario, sat with the Commission.]

(Toronto, 24th January, 1916.)

CHAIRMAN: You might be good enough to give us the benefit of your experience in New Caledonia, Mr. Colvocoresses, if you would. A. I was sent out to New Caledonia by what was called "The Nickel Syndicate" in December, 1901, as one of a party of engineers, and we spent about six months examining the various nickel deposits on the island; after that I was made mine superintendent of the Nickel Corporation Limited, which was an English company; they became afterwards subsidiary to the International Nickel Company, and I stayed there until April, 1905, in that position, having charge of their mining work on the island. I came away from there and went to Europe and back to the States, and went back again in December, 1906, and I was out there about six months on that second occasion, making a complete examination of all the nickel properties on the island. A re-examination in most cases, because I had seen them all before, practically, during my first sojourn there, and I think I can say that I knew at that time every producing nickel mine and every important nickel-bearing property on the island, many of which hadn't been opened up. One can get a pretty thorough idea of New Caledonia in four years' experience there; I had charge of the operations of some of the mines, and other properties I just examined. We were also operating cobalt and chrome mines there. I got over to the New Hebrides and to Australia a couple of times, looking over properties, but most of the time I was on the island of New Caledonia.

DR. MILLER: Were these nickel properties in the New Hebrides? A. None of any value whatever.

Development of Smelting on the Island

Q. What are they doing in smelting over there? A. Smelting had been urged by the New Caledonian government for a great many years. There were two or three abortive attempts to smelt ore back in the eighties, and in 1906, just the last time I was out there, they were building three smelting works. One was being built for the French Nickel company—the Rothschild company—one for the firm of L. Ballande, of Bordeaux, and one was being built by an independent French company up at a place called Tao. The Tao smelter has not operated for some four years now. They were making ferro-nickel direct from the ore by an electric furnace. They had very fine water power at Tao, and they utilized it for the manufacture of ferro-nickel, but they were not financially well backed and they had no valuable mines, therefore the thing didn't last very long or prove very profitable. The smelting operations of the French Nickel company are comparatively small at the present time. They are making a matte which they ship to France, and the firm of L. Ballande are also making a matte which they ship, partly to France and partly to the United States. Some of it goes to the United States Nickel Company in New Brunswick, New Jersey; and they had a smelter in Antwerp which has been taken away from them by the Germans, to which they sent some of their ores and some of the matte. The matte was refined there. I cannot tell you just where that matte is going at the present time. It is going into France, but at just what place it is being treated I don't know. The French Nickel company's matte as well as their ore goes to two places since the war broke out; it went to several before, but it goes now to Havre in France, and Glasgow, in Scotland; they have smelters and refineries at both those places. Before the war there was a large proportion of the New Caledonian ore that went to Germany. The Krupp firm bought heavily, and Basse and Selve and a Pappenburg firm, near Frankfort, bought, and they were laying in stocks of nickel for several years past; but at the present time it is all being used in France or England or Scotland, except the small amount that goes to the United States. Several years ago when I worked at the Orford Copper Works we treated quite a lot of New Caledonian ore. We bought about thirty thousand tons of it, the ore averaged about six per cent. nickel on the dry ore, and we smelted that up with the Sudbury matte, which was being sent down at that time. It didn't prove, however, very suitable for the Orford works and no more

was ever bought after 1901 or 1902. There have been cargoes of New Caledonian nickel ore brought to the United States and treated at some other plants, and it is probable that there may be cargoes again brought there. Some were treated near Baltimore, and some near Philadelphia. The present freight rate, or the last freight rate I heard of was 70 shillings a ton, which was equal to $17.50. The normal freight rate was 20 or 25 shillings. That makes it practically impossible to bring the New Caledonian ore to any point at the present time, and therefore, almost all the ore is being smelted into matte on the island of New Caledonia and brought over by the Ballande firm or the French Nickel people. I never visited either of those smelting works in New Caledonia. However, the process they use is practically the same as the French Nickel company use in Glasgow and Havre. They matte their ore with gypsum and ship the matte.

Q. What percentage of nickel does the matte contain? A. I think at the present time it is averaging about forty per cent., but I am not sure.

Q. They have to add sulphur instead of taking it away? A. Yes. There is no sulphur in the ore at all. The two sources of sulphur are iron pyrites and gypsum; iron pyrites is very scarce on the island of New Caledonia, and it doesn't pay to bring it from Australia as a rule, hence, gypsum is used for furnishing the sulphur. We investigated the sulphur proposition very carefully. I went to New South Wales, and I travelled over the island of New Caledonia looking for fluxes, and part of my trip to the New Hebrides was to look into the sulphur situation, there being some volcanic sulphur there. Unfortunately, the volcano was so active at the time I was there, that every little while somebody got drowned with the molten lava coming down the hill.

MR. SUTHERLAND: Why don't they smelt their ores there and ship only in the form of matte? Why do they ship the crude ore? A. Why is any established practice hard to overthrow? It was only when New Caledonia put a heavy tax on exporting ore, that they started up smelting. It is much more profitable, I believe, to smelt on the island than to ship the crude ore. We were shipping ore with five and a half per cent. nickel and ninety-four and a half per cent. waste. In that waste was included twenty per cent. water, and we were paying a freight rate, on the average, between $4 and $5 when I was out there. We did get some freight as low as $3.70.

DR. MILLER: Where was that to? A. To Glasgow and Havre and Rotterdam and Hamburg. The freight to New York was somewhat higher.

MR. SUTHERLAND: Are they now smelting the four or five per cent. ore which was formerly thrown away as waste? A. That is a little exaggerated. They sort the ore, and the average reject from the working faces on a good operating mine will contain about three per cent. nickel.

Q. And do they smelt that? A. No. At the time I was out there they were shipping good ore, and our contracts called for a minimum of six per cent. dry. That meant practically four and three-quarters per cent. wet. That was the lowest grade we could ship or produce at a profit. Now, in smelting on the island they could handle down to a minimum of about four and one-half per cent. dry, or say three and a half wet.

Q. Was the smelting expensive? A. Yes, because your fuel (coal) had to come from Australia, and we used to pay for it on the average about twenty-four shillings a ton; say six dollars. That may seem pretty cheap, but it was not a very good quality of coal. Better quality of coal cost around $7 and coke about $8. The sulphur obtained from the gypsum—well, the gypsum was not being worked when I was there, and I cannot give you any accurate figures as to what that does cost, but from the deposits which they work it should be mined and transported to the smelter for two dollars and a half a ton or perhaps less, and limestone for less than $2. If you ask me, I never knew why, from a commercial standpoint, they didn't smelt on the island, because it seemed the right thing to do, but they were making money without doing it, and they had smelters in France and a very heavy capital invested in them, and they decided to just leave well enough alone, and smelt in France and ship ore from New Caledonia. There was quite a profit in it even at that; then Ballande came along and planned to smelt on the island, and the government put extra duties on shipping crude ore, and the operating companies started smelting as well as shipping ore, and are making a lot of money at present also.

Features of the New Caledonian Industry

MR. GIBSON: The island is governed from France? A. Oh, yes, it is a French colony.

Q. Do the French government have anything to do with the mining industry? A. The Local Assembly puts on the taxes. It is limited self government, and the laws that are passed by the Local Assembly have to be confirmed by the Minister of Colonies in Paris, France, and if he chooses to veto a law, as he did sometimes when I was down there, it doesn't stand; but under normal conditions the Minister does not exercise that right of veto on industrial legislation.

Q. What is the attitude of the local government to the mining industry? A. Well, mining is by a long way the principal industry on the island. The island lives practically by this

[*G. M. Colvocoresses.*]

industry of mining, and the effort of the government has been to encourage mining by what they believed to be the best methods. Perhaps it hasn't always worked out that way.

Q. In future any legislation would tend to promote smelting in the island rather than discourage it? A. I think there is no doubt about it. I think they are unquestionably committed to that policy, and will continue to be so unless some new condition should arise.

Q. Do they seek to derive a revenue from the mining industry? A. Oh, yes.

Q. In what way? A. By taxing the mining land that was held and by taxing the output of the mines, as exported. We paid a land tax on all our holdings, and in addition we paid an export tax on all our ores, and then there were heavy duties on the ships that came to freight the ore away.

Q. Do they collect a tax on the matte? A. Yes, they collect a tax on the matte, but it is a smaller tax proportionately than the tax on the ore. They have endeavoured to make it to the advantage of companies to smelt.

MR. SUTHERLAND: They discriminate against the export of crude ore? A. Yes. One feature down there was the enormous amount of land that was held by mining companies, and the comparatively small percentage of it that was worked, and they put on a graduated land tax that started in with a small holding at a comparatively small figure and worked up, so that a company that was holding twenty thousand hectares was paying five times as much per hectare as a person holding a hundred hectares.

DR. MILLER: Are there any leases held down there? A. Yes. There are many cases where a man will take a contract to furnish one shipload of ore, or sometimes a lesser amount; he takes a royalty lease on a mine, and sells the ore to one of the large companies, and then along with other materials it is shipped out of the country, or taken to the smelter.

The Question of Labour

MR. YOUNG: Do you use native labour in the mines, largely? A. No, the native labour is almost useless. The natives are Kanakas, and they are no good except out in the woods. They use in the main Japanese and Chinese coolies for the mines, and for a while I was there we brought in a lot of Austrians, and then we had ex-convicts, too.

Q. Does France use New Caledonia any longer as a convict colony? A. Not since 1900, but I suppose there are still ten or twelve thousand convicts and ticket-of-leave men on the island.

MR. SUTHERLAND: How would your costs be there? A. It depends very largely on the ore body you are working. The island is pitted all over with little nickel deposits; nearly all of them are very small. I only know of two mines there that produced more than 200,000 tons of ore. That seems insignificant to a mining man. Most of the mines produce 20,000 to 100,000 tons. That was considered a good mine, but there were a great many of them. Now, if a person happened to strike a mine where the over-burden was light and the location was fairly good, close to a river where you could lighter the ore down, or close to a little railroad that ran into the harbour, the actual mining of the ore was rather cheap. You had, of course, to charge your installation against the ore that was produced. Sometimes ore bodies occur in groups. There was the plateau of Thio, which the French company worked for a number of years. I think they took out about six or seven hundred thousand tons, but they operated from six to seven different mines, all connected by a little tramway, one with the other.

DR. MILLER: How far away would that be? A. Some a quarter of a mile, and some a mile. They worked around the edge of the plateau. We considered that when we got ore on board ship for $4 a ton, including general and overhead expense, we were doing pretty good mining; the direct costs were sometimes as low as $3 per ton.

MR. SUTHERLAND: Have you any idea how much it costs to make nickel from the New Caledonian ore? A. Yes, I know pretty well, or rather I did know pretty well five years ago. I don't say this is the figure to-day, because I don't know it to-day, but it cost approximately a minimum of nineteen cents a pound to make refined nickel from New Caledonian ore at that time. That was under favourable conditions. There was a lot of nickel made from New Caledonian ore that cost twenty-one to twenty-four cents a pound: That includes everything; mining, shipping, smelting in Europe and refining and marketing.

Increasing Cost of Production

MR. GIBSON: Would matting in New Caledonia and refining in France lower that figure? A. I think it should, but how much I am unable to tell you exactly. I can tell you this, though, that the cost of producing ore has gone up in New Caledonia considerably since I was there. The basis we used to figure on was so many francs per kilo, nickel content. That has gone up about twenty per cent. in the last year and a half, even buying at a New Caledonian port. The reason of that is, first of all, the labour situation. They cannot get the Japanese and Chinese coolies as easily as they could. They have to pay them more now, and whereas we used to sell ore at the time I was out there for sixty to seventy-five centimes per kilo of nickel content in ore (12 to 15 cents) f.o.b. a New Caledonian port, the buyers pay 16 to 20 cents per kilo at the present time. A kilo is 2.2 pounds in

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round figures; its cost equals seven to nine cents a pound on board ship New Caledonia. Now, you can figure from that up; freight and insurance roughly was five cents a pound under normal conditions—it is a great deal more now; it was sometimes not quite as high as that, but that will stand as an average—and say smelting and refining charges to the oxide six to eight cents a pound, and you bring it up to twenty-cent nickel. A low grade ore could be purchased for a lower figure per kilo of nickel contained, but the freight and smelting charge on such an ore would be correspondingly higher, so that the cost of the refined nickel would be nearly the same, in fact the cost would be a little less from a high grade ore. Now, to-day, if they ship a forty per cent. matte, that will alter those conditions very materially. I never have obtained accurately the cost of the nickel matte from New Caledonia, but I have good reason to believe that it does not fall below, at the present time, eighteen or nineteen cents a pound nickel contained. Under normal freight conditions it would probably be down around sixteen cents, or possibly less, and the refining and selling cost would have to be added.

MR. SUTHERLAND: In those open pit mines won't you lose a lot of time in the rainy season? A. I have seen the time when we worked only eleven days out of the month. Every year during the rainy season, which is three to four months long (beginning in December, which is summer there, and continuing to about the middle of March), you can figure on an average of about twenty working days for three months. Of course, we don't pay the men when they don't work.

Q. And how would that affect the smelter? A. Not to any extent; they work in sheds. They have their stock in before that wet weather comes on. The only way it would affect them is that the ore comes in wetter, often containing twenty per cent. moisture.

Q. That is not combined water? A. Not combined. You heat to 100 degrees centigrade and it all goes off. Now, naturally, in the rainy season they get some wet ore in the smelter.

MR. GIBSON: Is the climate in New Caledonia objectionable to white men? A. Not more than, say, that of Cuba. Cuba is about as far north of the equator as New Caledonia is south. The climate is very nice, except for the four months of the rainy season; it is a beautiful climate. But there is one thing there that ought to be mentioned, and that is that there are certain sections of the island where the mosquitoes are such a pest that they make it almost uninhabitable. That doesn't hold for most of the nickel mining sections, fortunately.

Q. Is there any yellow fever? A. No, no yellow fever or malaria. It is a very healthy country.

DR. MILLER: Good water? A. Yes, good water. You could go all over the island (it doesn't take very long to get around it) and in places you can get a river every kilometer you travel; that is nearly two to the mile. Rivers and streams all over the island.

Q. And are the mines far in the interior? A. A few of the mines are overhanging the sea, almost, and in some cases they just stretch a ropeway out to the lighters and the ships, too, while other mines are right back in the centre of the island. The island is nowhere more than thirty miles wide, so you don't get very far inland at that.

MR. YOUNG: What length is it? A. Two hundred and forty miles.

MR. GIBSON: Are the nickel deposits spread all over the island? A. Except at the north and south ends. The nickel deposits occur in the peridotite formation, which covers about one-third of the entire island. It starts in ten miles north of the southern end, or fifteen probably, and runs up to within about forty or fifty miles of the north end, but on the west coast there are alluvial plains which run out from the peridotite mountain range and have a width of ten to fifteen miles. Also, there are sections that are limestone (they are really coral limestones) and they carry no ore deposits, while at the very north end you get chlorite schists and a Cambrian formation, or Paleozoic anyway, which is much older than the peridotite. The French government used to import coolies from the French sections of Asia; Tonquin, Indo-China, and Pondicherry, and they used to bring these men over in batches of 100 or more with a regular contract, a five-year contract. You went to the French Immigration office and said you wanted 100 Chinamen, and you would have them on the next steamer. The cost of transportation was paid to the government, and at the end of a period of five years if you wanted to renew the contract you could, if they were agreeable. A certain amount of money was paid to them; about $4 a month was the average for their wage, and in addition to that you had to feed them and clothe them, for which certain amounts were provided, and you had to set aside, beyond that, enough money to pay their passage back to China. The government took half their wage and put that in a deposit account, and then when they went back to their homes half of their wage for the time they worked was given to them in China, but not before. The man who worked very hard over there in five years might accumulate about $250. Then we used also to contract with a Japanese company; it was an independent concern, but the Japanese government fostered it; and they used to supply us with Japanese coolies. They were a little more expensive; we paid them seven or eight dollars a month and also provided them with food, clothing and their return passage. Also we used to get Hindoos and Javanese occasionally, and for certain kinds of labour we employed the New Hebrides natives, and then we had the ticket-of-leave French convicts, and lastly, Austrians. It shows how inefficient that coolie labour was when we could afford to

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get Austrians over and pay them $1.50 a day as against that coolie labour, and for some work we found them quite economical at that.

Q. You got good labour from them? A. Yes. We paid $1.50 at first, and then the wage went up to $2, and at $2 the company didn't want them.

Ore Reserves

Q. What about ore reserves in New Caledonia? A. For a basis of calculation of the ore reserves, the only mines that have ever been systematically prospected and developed were the mines of the French Nickel company. They were shipping approximately 125,000 tons of nickel ore per annum, and they could see reasonably certain thirty years' shipments from their properties. Aside from that, they had a lot of more or less unexplored territory which was certainly nickel-bearing. We owned the second largest group of mines on the island, the International Nickel company I mean, and we never really made—well, I don't think it would be fair for me to say what our estimate was.

MR. YOUNG: What is that French Nickel company? A. Société le Nickel. It was controlled by the Rothschilds, and they were the principal producers of New Caledonian nickel. Two other companies were absorbed into the International Nickel company, the Société Minière Caledonienne and an English company, the Nickel Corporation, Limited.

DR. MILLER: Is there much difficulty in visiting these mines? A. Not as a rule. If a person were introduced in any way, there would be no objection. None of us allowed everybody that came along to go round, because the character of the people that were wandering around New Caledonia was not very desirable, but anybody that really had any standing or was properly endorsed was always taken up and allowed to visit them.

[*G. M. Colvocoresses.*]

SECTION L

KRUPP'S NICKEL MINES IN NEW CALEDONIA

Evidence of Bedford McNeill, A.R.S.M., Past-President of the Institution of Mining and Metallurgy

(London, 24th March, 1916)

CHAIRMAN: I have explained to the other members of the Commission that Dr. Miller and I have had some conversation with you regarding certain New Caledonian nickel properties which formerly belonged to one of the Australian banks, and which ultimately were sold to Krupp's. A. Which are believed to have been sold to Krupp's. I have prepared a memo. for you.

Q. You are going to give us such information as you have respecting them? A. Yes.

Q. Perhaps I can leave it to you to start the ball rolling? A. The properties belonged to an Australian bank, which got into difficulties at the time of the Australian crisis, and eventually were offered in London. I was asked to advise the owners as to the opening up and working of the properties, and the consequence was I accumulated a good deal of general information about nickel, any of which, if it is of any use to you, is at your disposal, including the prospectuses of various companies.

The Sale to Krupp's

Q. Those will be very interesting to us. A. I have the sort of technical "flotsam and jetsam" which one collects in working up a subject. We sent out and had the properties reported upon by Capt. Harvey; I have a copy of his report here, which is at your disposal. The samples were assayed by yourself, and your assays were put in his report. Eventually the capital requirements were found to be beyond the means of my clients at that stage, and then—I do not know how—they got into negotiation with a Brussels company. The company was the Compagnie Silesienne des Mines, with an office at 59, Rue de Namur, Bruxelles. It was a limited company with a capital of 6,900,000 francs. The correspondence with Brussels was signed by the chairman of the company, Arthur Schmidt, and another name which is undecipherable. The money to complete the transaction was remitted from Germany by Messrs. Delbruck, Schickler & Co., Berlin, through Messrs. Williams, Deacon, London. The company for whom I acted owned ten-twentieths of the whole property, which was sold in June, 1911, for £13,333 6s. 8d., making the price for the whole £26,666 13s. 4d. The names of "Frielinghaus" and "Director Sorge" occur in the correspondence. I do not know whether "Sorge" was a director of Krupp's or not.

Q. Were any negotiations started or suggested with the International Nickel company before Krupp's took it? A. I cannot say.

Q. When you were showing us the map of New Caledonia, there was one big concession marked in red, and then you mentioned in addition, the possibility that certain of the smaller concessions were apart from that red-marked portion; do you happen to know whether that is so, that is, whether any of this £26,666 was spent for additional properties? A. I imagine not.

Q. It was all in the one block? A. Yes; it is all in the one block that is coloured on that map. There were several tracings; they started with a smaller area, and then they eventually increased it to the ultimate area, which is the one that is marked on that map.

Q. It would only mean an extension—not somewhere else as well? A. That is so.

MR. YOUNG: A contiguous part? A. Yes; it is absolutely one piece covering an area of some 45 square miles.

CHAIRMAN: Have you any knowledge as to whether it is still working? A. Not the slightest. I have not been able to find out from the people who sold it. In fact, they cannot produce to me what I asked for, namely, the actual agreements for the purchase. Apparently all the agreements and so on, were handed over to Williams, Deacon, here in London in exchange for the money.

Q. Do you know anything about the type of ore, its assay value and so on, which was shipped before this Australian bank took an interest in the property—whether it was 7 per cent. or 8 per cent., or where it went? A. At that time nothing less than 7 per cent. was shipped from New Caledonia, that was the shipping grade. Anything below 7 per cent. was rejected and put on one side.

Q. And now it has gone down to about 5 per cent. Have you any of the actual or estimated costs for mining and smelting or for refining any of the products? I expect a

good many were put before you? A. Yes; I have the cost of labour, and the different classes of labour, convict labour, and so on.

Q. Could we have that? A. Yes, certainly; you can have anything else that you think will be useful. Of course it is old.

Q Yes, but still it would show what the changes had been? A. Yes.

The Properties Described

Q. These changes are still taking place, and they can treat lower grade ore than they used to in the past? A. I have a memo. under date of 10th January, 1900, from J. H. Stanley; he is one of the men who went with L. Koch. Koch reported on the property, and was described as Ingenieur diplome des Arts et Manufactures, Membre de la Société des Ingenieurs Civils de France. Koch was formerly a manager of Rothschild's. Stanley says the French Nickel company's mines are becoming lower grade. I have Koch's "General Conclusions." "The three groups form an area of much importance. The larger the output, the greater the economy of working" That is quite sound. "The heaviest expenditure will be making the tramway to the shore. It will take 25 miners three to four months to give the group a first regular output of 500 tons per month."

Q. This is an important point? A. Yes.

"It is important not to hamper development by too much haste in output. At the "Croix du Sud Mine, (the ore of which resembles the Eastern group) but not so rich, 300 "tons are at grass in two months, each 24 working days of 8 hours, and with 20 men. The "tramway to work the eastern and Balman groups will have to start from the left bank, to "skirt the plain from the left bank as far as the Mine Bechet, cross the Cambouie, and "make use of right bank as far as below La Combe and Nicholl's stores. River to be "crossed either by bridge or cable. At mouth of river storage sheds will be necessary. "There is safe anchorage. Three passes through the N'Goe Reef. A few miles north is "Port Bouquet. Two thousand tons should be produced before undertaking the establish-"ment of transit. Once the opening of the principal working places has been performed, "a few months will be required to obtain an output of 1,000 tons per month."

Q. Apparently he thinks that is a reasonable estimate for the mine even as a start? A. Yes. Then there was a man named Bernheim who had certain mines. I think he got into one of the other companies.

"In 1892, Bernheim produced 250 tons a month, and in 1899, that is seven years later, he "was producing 4,500 tons a month. At Nepoui he employed 400 convicts and 150 Tonkinese, "making a total of 550, and working 25 days a month of eight hours." I have a note here: "Steam tramway at Bernheim's mine at Nepoui 22 kilometres cost 600,000 francs, which is "equal to 25,000 to 30,000 francs a kilometre."

Q. Did you not say the other day that it was something about four miles from the shore? A. About 5½ miles, I think. He is further back, but still it may be skirting the shore; it may be lengthwise.

MR. GIBSON: All you have read has reference to this area marked pink on the map, has it not? A. Yes, except the last reference about Bernheim.

CHAIRMAN: With regard to Bernheim, that is interesting, but it has nothing whatever to do with the property? A. No. There are other mines in the same way.

Capt. Harvey's Report

DR. MILLER: In order to get this area located properly on the map, have you any brief description of it? A. We have our own man's report. Capt. Harvey whom we sent out described it in this way in his report, which is addressed to myself, dated London, 6th December, 1902, and which I will read:—

"Having received your instructions to examine and report on the nickel properties "situated as mentioned below, I arrived in Noumea, New Caledonia, on July 25, leaving "again on August 28th. Situation:—The properties are situated on the east coast of New "Caledonia, within the region of the Camboui, N'Goe and Humboldt in the Second Arrondise-"ment or Province, the nearest point from the coast being about 5 kilometres."

CHAIRMAN: That is more like what you mentioned? A. Yes. "Accessibility.—The "valleys of the rivers Camboui and N'Goe by which the properties are accessible are reached "from Noumea, distance 160 kilometres, by coastal boat. The river Camboui is navigable "by row boats, with difficulty, for a length of 3¾ kilometres from its entrance. Altitude:— "The properties are situated at an altitude of 125 to approximately 1,000 metres above "sea level. Names and area of property:—There are seven properties bordering one on "the other, which comprise practically one complete block. The names and area are as "follows."

Then they are set out. The total is 11,621 hectares, equal to 28,704 English acres, or about 45 square miles. There are five "Young Australias." "Pera" and "Galata"

Q. Are those the names of the properties? A. Yes. "Titles.—The seven properties have been applied for in concession and are held at present as follows." Then the titles

[*Bedford McNeill.*]

are set out. He gives the rent as 50 centimes per hectare—under 2d. per English acre. The export duty is 25 centimes per ton—about 2½d. per English ton.

"Prospecting license, (permis-de-recherches) is issued for twelve months, and is re-"newed annually on application and the payment of dues, namely, 40 centimes per hectare. "When application has been made for concession titles, no annual renewal is longer necessary "provided the survey fees, concession rent, and title deed fees are paid. No labour condi-"tions or restrictions are imposed."

Then he refers to water and wood, and then all the mine openings are dealt with, and so on. Do you want that?

Q. I suppose there is a date to this? You mentioned October, but you did not tell us the year. A. This report is dated December, 1902.

MR. YOUNG: The sale was not made till June, 1911? A. That is so. Of course we hoped to work it, and if we could have raised the working capital my clients would have kept it.

DR. MILLER: There are some geographical features on this property which might be mentioned, and put on record. Mount Humboldt is the highest; that is 1,634 metres. Then Mount Nekando lies just outside. Then there is Mount Monyandouman; that is 807 metres.

MR. YOUNG: Then then are two rivers, the Camboui and the N'Goe? A. I have another report but it is marked "private." I can read extracts:—"As the result of a personal "visit to the French colony of New Caledonia in July and August, 1901, I have the honour "to present the following report and statements concerning the nickel and chrome mines "and mining properties enumerated below and owned by Messrs. Thomas Maning, Frederick "Moncassin and Henry Boyle, and Joseph Henry Stanley as attorney for the British and "Australian Assets Company, Limited."

He gives the area as 28,704 English acres, or about 45 square miles.

"The Nickel mines.—These seven mines are all co-terminous, thus comprising one com-"plete and compact block. Accessible by the Rivers Camboui and N'Goe to one common "loading or shipping port. Titles:—According to the mining laws of New Caledonia, com-"plete titles cannot be issued until surveys have been made. Surveys are not proceeded "with under 'permis-de-recherches' or annual occupation, which has to be renewed yearly. "When application has been made for concession titles no annual renewal is longer necessary "providing the survey fees, concession rent, and title deed fees are paid, there being no "risk of eviction, all rights being strictly secured"

The rent is stated as under 2d. per English acre, and the export duty is 2½ d. per English ton.

"There are no labour conditions or restrictions. Nickel mines:—The prospecting having "advanced sufficiently on the nickel deposits of the Young Australia, Balman Spur of the "Pera, and the remaining part of the Pera, expert opinion was obtained in the person "of Mons. L. Koch, Ingenieur diplome des Arts et Manufactures, Membre Société Ingenieurs "Civils, France. An extensive report was prepared after his visit to the properties and "inspecting of the prospects of the deposits. Samples were taken at some 35 prospects and "assayed by the government chemist, Mr. T. Moore, the results ranging from 4.94 per cent. "metallic nickel to 20.42 per cent. metallic nickel, the average being 11.81 per cent. metallic "nickel. Nickel in sample dried at 212 degrees F.—7.03, 4.84, 4.15, 3.6, 5.26, 8.34, 4.77, "2.81 and 18.61."

"Development:—The operations on the deposits have been done by open cut or quarry "method, and will be continued on this principle. The altitudes and general nature of the "deposits encourage this class of working. Nickel ore occurs on the sides of the mountains, "in this case the lowest altitude being about 600 feet above sea level, and the highest about "2,050 feet above the same datum. The 35 quarries or open faces extend in altitude from "600 feet to 2,050 feet and along the valley for a distance of 2 miles, and run both in "altitude and horizontally in a fairly continuous belt. This refers to the Camboui river "or as far as development has been done with a view to extensive operations."

J. H. Stanley's Account

Here is a "Report of the Mining Concessions in New Caledonia received from Mr. Stanley, 1st January, 1900 by Mr. Maning." The following may be interesting

"At this juncture it is well to draw attention to the fact that there are for all prac-"tical purposes only two countries producing nickel in any quantity, namely, New Caledonia "and Canada. The latter country, however, has to contend with climatic disadvantages, in "the shape of severe winters, etc., which for certain periods of the year cause work to be "entirely suspended. I further learn that in Canada the ore is mixed with refractory "metals rendering its application somewhat difficult, and this is further evinced by the "fact that Messrs. Carnegie, the large steel manufacturers in America, have recently found "it to their advantage to import nickel from New Caledonia in spite of the fact that they "had it almost alongside their doors in Canada." That would be before the Mond process came into use, would it not?

[*Bedford McNeill.*]

CHAIRMAN: I think so.

WITNESS: Then he describes his visits to the properties at great length. Speaking of a property, which he says is owned by the Société le Nickel, and is near this particular property, he says:—"They, the Société le Nickel, had about 250 tons already picked for "shipment, and had opened out from 1,500 to 2,000 tons, and finer nickel has not been "discovered anywhere in New Caledonia, some of it going up to 18 per cent. Mr. Nicholls "estimates that it will cost him about 20 francs f.o.b. for 8 per cent. nickel, and this will "leave him a net profit of about 20 francs, but he admits that working as he is with "borrowed capital and in a very cramped way it is costing him far too much." "He reckoned "that each miner produced 20 tons per month and he was paying his men 4½ francs per "day, but as the men buy from him their stores at a profit to the mine of from 70 to 100 "per cent., it probably does not cost him more than about 2 francs a day for his men."

Here is an interesting point: "Bernheim's mines, which were recently purchased by "the International company for £100,000 sterling, generally produce from 1,000 to 2,000 tons "per month. The Société le Nickel make about 3,000 to 5,000 tons per month."

At page 14 there is this:

"Cost:—Working in a large way, there is no reason why this should not be reduced "to say, 15 francs per ton f.o.b., and if we could obtain an average of 40 francs f.o.b. it "will at once be seen how large a profit could be made considering the quantities to be "handled. The demand is practically unlimited."

"Treatment:—Some years ago a smelting company was established in New Caledonia "for the treatment of nickel and about 500 tons was produced, but it was subsequently "found out that the process was all wrong, and the 500 tons after remaining in London "for many years were sold at a great sacrifice. It has been proved that it is less expensive "to take the ore as it is to the nearest spot where the necessary chemicals are obtainable "rather than bring the chemicals to New Caledonia."

WITNESS: I have here some figures which are taken from the prospectus of the Consolidated Nickel company

CHAIRMAN: They are presumably correct? A. Yes.

F. L. Merry's Report

Q. I think that was not a company that you were in any way interested in? A. No. It does not seem to have a date on it, but reference is made to the Institution proceedings of 1900. I see there are some figures here taken from the prospectus which are rather interesting. There is a report by Mr. F. L. Merry—that will be the Swansea Merry.

Q. His people have been in nickel and cobalt right from the beginning. I understand that is his report? A. Yes, as it appeared in the prospectus of the Consolidated Nickel company.

Q. That will probably be after 1900? A. Yes. " The following is the report made in 1899 on the properties to be acquired by the company (with other properties not so acquired) by Mr. F. L. Merry for Messrs. H. H. Vivian and Co., Limited, of Swansea, who are one of the principal smelters of nickel ores in Europe " These particulars are rather interesting:—

"Output of a local mine delivered on the seaboard was 55 centimes per kilo for the "nickel contained. Fifty-five centimes per kilo (equals 2.2 lbs.) equals £23 6s. 8d. per ton "(2,240 lbs.) of Ni (metal). Freight is so excessively high, viz., 28 to 30 shillings a ton, "which with other charges equals 3d. a pound on the nickel contained in the ore that advises "smelting to matte containing 60 to 70 per cent. nickel. Coal at Newcastle, N.S.W. 4 "shillings 6 pence to five shillings 9 pence per ton; coke about 18 shillings per ton; freight "10 shillings per ton. All fluxes can be obtained in the island. Estimated cost of smelting: "materials, £1 7s. 0d.; wages, 6s. 4d. equals £1 13s. 4d. per ton of ore. One ton produces "224 lbs. of 60 per cent. matte; that equals 134 lbs. of metallic nickel, which divided into "£1 13s. 4d. for smelting equals 3d. per lb. of nickel in the matte." "Cost of delivering "matte for refining in Europe; cost of ore, 2d.; smelting charges, 3d.; freight, 0.32d.; "insurance, 0.15d.; packing, 0.21d. equals 5.68d. per lb. Ni., or say 6d. per lb. Duty on "exported ore 2½d. per ton. No duty on matte or refined metal."

The report continues:

"Annual output, 50,000 tons at 7 per cent. equals 3,500 tons of nickel at a cost of 70 "pounds sterling per ton Ni, equals £4 18s. 0d. per ton of ore. If nickel is taken at £125 "then £125 minus £70 equals £55, which multiplied by 3,500 tons gives a profit per annum "of £192,500, less administration expenses, general charges, depreciation, etc. Average price "of nickel last five years £125. Present price of nickel £165 a ton—I have the date here —December, 1901.

MR. YOUNG: Does this refer to the same property—the Young Australia? A. No. This was the report, or rather these are extracts from the report of F. L. Merry, of Swansea.

Q. The prospectus is dealing with a different block of properties? A. Yes.

[*Bedford McNeill.*]

CHAIRMAN: Generally speaking, the figures would apply to both, or a great many of them would? A. Yes.

WITNESS: Here is some general information.

"The discovery of nickel ore in New Caledonia was in 1864 It was first mined in "1874. Société le Nickel acquired mines at Thio in 1880, but did not commence active "operations until 1887, since when they have produced 250,000 tons of 7 per cent. nickel "ore. The whole industry is practically in the hands of Société le Nickel and Nickel "Corporation, Limited."[1]

MR. GIBSON: There is a reference there to the acreage of the holding of the Société le Nickel.

MR. YOUNG (reading): "Société le Nickel owns mines at Thio, Canala, Kowaoua. Nickel "Corporation represents an amalgamation of properties at Nepoue, L. Bernheim's forming "the centre. Bernheim held 20,000 hectares, equals 49,420 acres, of concessions on spurs "of the mountains between Peoue and Nepoue rivers, building 20 miles of tramlines to "connect with coast at Moueo. This holding with the unexplored concessions owned by the "International Nickel Corporation, 60,000 acres in all, were recently acquired by the Nickel "Corporation Limited,[1] capital £750,000 sterling, floated by the London and Globe Finance. "Ores are found only in the serpentines in irregular veins and fillings of the shattered "surface rocks forming stock works. No special rules can be laid down for these ore "occurrences, but the mining centres follow specific lines, and six mining areas have been "established. There is no doubt as to the hydrothermal nature of all the nickel veins "and deposits. The ore always consists of the hydro-silicate of nickel and magnesia, some- "times pure, but more often associated with a silicious gangue, red clay or fragments of "decomposed serpentine."

"The secret of success lies not so much in mining, but transporting the ore to the "sea board."

"Official statistics, 1st July, 1892. The total mines in operation 324 (80 actively) "comprising an area of 48,956 hectares, equals 120,921 acres. Production equals 60,000 "tons per annum and still increasing."

This is from a paper written by Mr. Garland, and published by the Institution of Mining and Metallurgy.

Evidence of C. Williamson Milne and Friend (Mr. X.), of London, Eng.

(London, 14th April, 1916.)

CHAIRMAN: I think the negotiations for the sale of the "Young Australia" properties were conducted by you, Mr. Milne? A. (Mr. Milne): Yes; the whole of them were conducted by me with one of the directors of Krupp's.

Q. This would practically refer to the notes we got from Mr. Bedford McNeill? A. Practically, yes, except that I conducted the negotiations myself. I do not think McNeill was ever present, and I do not think he ever met the gentleman with whom I negotiated. Krupp's directorate is, I believe, made up practically of a group of managing directors, each one of whom controls a particular branch of the business. They are all more or less specialists, and the man who bought these properties from me was the mining specialist on the board of Krupp's. He represented Krupp's. Krupp's owned a big iron ore mine in Spain, the Orcanera.

Sold to Krupp's in 1912

MR GIBSON: At Balbao? A. Yes. Another firm on the north-east coast of England, whose name I cannot for the moment remember, had a certain interest in this big property in Spain, and Krupp's had a certain interest. This man came to England to attend these board meetings every two or three months. When he was over last he came and saw me about these properties in New Caledonia. There is not the slightest doubt about it, Krupp's had had their agents out there, and had extensively examined these properties and knew exactly what they were buying, and they gave me a very good price for the properties, which we had held for about fifteen years. We took them up in 1896 and sold them about four years ago.

The history of this is as follows. My friend had occasion to be in Noumea on other business in which I was interested, and one night, sitting in the club there, he happened to be chatting with a Britisher, a New Zealander, who subsequently became the British Vice-Consul in Noumea. This man said, "I have just found an extraordinary paper in my late father's desk." He was asked what it was, and he said, "It is a tracing of a property said to be the richest nickel property in New Caledonia. It was given to my father by a native chief who had known all about it." My friend said, "Have you never

[1] The stock of the Nickel Corporation Limited was acquired by the International Nickel Company.

[*Bedford McNeill; C. W. Milne; Mr. X.*]

done anything about it?" and he said, "No, I have never bothered about it at all" My friend wondered if it would not be worth exploiting, and when he went back to Sydney he organized a little syndicate. They divided it into twentieths, and each took so many twentieths and put up so much money. Another friend of ours, the Hon. Henry Boyle, brother of the late Earl of Shannon, was in Sydney at the time, doing nothing He was a big, hefty chap and he offered to go out and exploit it. The man, whose father had left the paper, took a certain number of shares, and we gave Boyle a couple of shares for the work he did. Boyle went over; he took a launch from Noumea, went up the coast to this place, and stayed on that property I suppose for nearly two years.

(Mr. X.): Yes; I went with him.

(Mr. Milne): They lived in a corrugated iron hut.

(Mr. X.): We took it with us and put it up.

(Mr. Milne): Boyle stayed on and pegged all this land out—a tremendous area.

(Mr. X.): You had originally about 90,000 acres and we cut it down to about 30,000 acres afterwards. A lot was thrown out.

Offered to International; Also to a French Firm

(Mr. Milne): Boyle sent home samples of the ore. After it was all pegged out I tried to get the nickel combine in this country interested. I also tried to get the American people interested, and I had a long chat with Mr. Monel, who was introduced to me by Col. Hunsiker; but nothing came of that; they were doing very well. He had just taken over Col. Thompson's property, and it meant putting up a lot of money. Then we had negotiations with a French group, Chalas & Sons. Chalas was going to do something with it, but it never came to anything.

CHAIRMAN: That was Chalas senior? A. Yes; it was the old gentleman I dealt with, and the sons came along subsequently. That never came to anything. Then this man, Bergrath Frielinghaus, one of the Krupp directors, came and negotiated with me. He made no secret about being a director of Krupp's. When the property was transferred, it was to a Belgian syndicate whose headquarters were in Brussels, and all the money was paid through Brussels, in exchange for which we handed them over the shares. They transferred the shares, and the whole thing was done in regular form. Whether they turned it over to another company or not I do not know, or whether they simply took over our title just as it was. They paid the money, and took the assignment of the shares, and that was the finish so far as we were concerned. Frielinghaus was one of the nicest men I ever met; he was geniality itself. I never want to do business with a nicer man or a straighter man. In his dealings with me his word was as good as his bond; he paid up to a penny and did everything according to his agreement and his promise. He invited me to go to Essen, and I went there three years ago. I was taken over a great part of Krupp's works. That was twelve or eighteen months after we put the deal through.

Ore Shipped to Norway for Refining

MR. GIBSON: Have they worked the property? A. I heard that one of Krupp's vessels laden with nickel ore from New Caledonia had been stopped before it got to Norway That vessel was, I believe, taking over ore from New Caledonia for Krupp's to be treated in conjunction with the low-grade Norwegian ore. They experimented with it, and they found they could enrich the low-grade Norwegian ore with this ore from New Caledonia. It is only assumption on my part that it came from our property.

(Mr. X.): I should doubt it, although it is one of the easiest properties in the world to work. You could bring it down from one peak to the other, and then there was a very good river that was navigable right up to the foot of the mountain. The whole trouble was the loading. The prevailing wind was always the difficulty we had to contend with. There was a certain amount of shelter from the little island just off the mouth of the river, but it would require a good deal of buoying.

(Mr. Milne): I have no doubt they have records in New Caledonia. I believe that ore came from our property, because Frielinghaus was so anxious to get the thing through and get it finished. Krupp's were keen to get a start made, and I do not think they let the grass grow, especially having regard to the knowledge they must have had of the property.

(Mr. X.): In any parts that were opened up one simply dug out the ore.

(Mr. Milne): A very large amount of it was weathered. Mr. Moncassin had a few shares; Maning, the New Zealander, had a good many shares. Moncassin sold to Maning, and Maning sold through me to the Belgian company controlled by Frielinghaus.

(Mr. Milne): You could not get to that property of ours by land from Noumea, I think? You had to go up by steamer?

(Mr. X.): Yes; you had to go round. You arranged with the steamer which goes from Noumea; it goes round a reef and runs on to the New Hebrides. I used to go down

[*C. W. Milne; Mr. X.*]

with this boat, and arrange for them to stop off the mouth of the river. The boat would come and meet us. Then I arranged with the steamer coming back from the New Hebrides to call there and pick me up. On one occasion I wanted to see Rothschild's mine, and I chartered a native boat and sailed about fifty miles up to Thio. Of course there is a big town there. Then from Thio to Noumea is a very good road.

(Mr. Milne): Rothschild is the Société le Nickel, is he not?

(Mr. X.): Yes.

(Mr. Milne): At the time we were in it, it was reported that they were being worked out.

(Mr. X.): Yes; they were always taking up more country, and they have a lot of undeveloped property, because the general report was that the whole southern part of the island was all nickel on that side. There is no reason why it should not be; it is all the same formation. But it is very un-get-atable and the whole difficulty is loading. You have the hurricane season from November till May. It is dangerous. You cannot load there at all unless you make special arrangements for it. Then during May, June, July, August, September and October you are quite safe. In the plans I had drawn up, which Mr. Milne was going to work, we were going to bring the stuff down where the aerial rope is at the foot of the mountain and create a large dump of the stuff there, build a jetty, and load during those six months of the year, taking the whole of the supplies then. The other side of the island, where the chrome ore is, is open the whole of the year round; there are magnificent harbours there.

(Mr. Milne): We were working the George Pile and other chrome mines we were interested in for a number of years, and we made a lot of money out of them. Chrome is the simplest thing in the world, because you just dig out the side of the mountain. That side is very easy to work; there is abundance of water, and all this earth is thrown into long races. From every ton you get 5 per cent. of this chrome, and that paid handsomely.

Q. Even at the old price? A. (Mr. X.): It was four pounds a ton; I think it used to be four pounds a ton delivered in Glasgow.

Q. Something like that; but it went down as low as 50 shillings at one time, and that seemed to knock everybody out of it. A. Yes.

(Mr. Milne): It was 50 per cent. chrome, was it not?

(Mr. X.): You had 95 per cent. of earth, yellow clay, and the rest was like black sand, exactly the same. We worked that with Dalmatian labourers. The vessels used to anchor just alongside the bank.

(Mr. Milne): I suppose you have seen the paper written by Danvers Power?

Q. Yes, and we have an old one by Garland; that is a good deal older. Danvers Power's is a good paper.

[C. W. Milne; Mr. X.]

SECTION M

DIAMOND DRILL RECORDS IN FALCONBRIDGE AND GARSON, 1916

The following interesting series of records of diamond drilling in search for nickel-copper deposits, and the proving of the same, in the townships of Falconbridge and Garson, in the year 1916, have been kindly furnished by the E. J. Longyear Company, exploring engineers. A further description of these deposits will be found in Report, in the Chapter devoted to Nickel Deposits of The World.

HOLE NO. 23, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0'	128'	128'	Surface	176'2	178'5	1.95	None	1.95
128'	153'	25'	Norite with sulphides	196'9	197'6	1.11	.47	1.58
153'	176'2	23'2	Basic norite	206	209'8	1.44	1.71	3.15
176'2	178'5	2'3	Norite and ore	212	213	.14	1.98	2.12
178'5	196'9	18'4	Schist	215	220	1.36	.80	2.16
196'9	197'6	0'9	Schist and ore	220	225	1.24	1.89	3.13
197'6	206	8'6	Basic norite	225	230	2.32	.63	2.95
206	245	39'	Schist and ore	230	233'6	1.84	None	1.84
245	265	20'	Quartzite—graywacké	237'6	238'4	1.08	5.12	6.20
				238'4	245	1.54	.86	2.40

HOLE NO. 24, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0'	123'	123'	Surface	177'6	180'8	3.22	None	3.22
123'	177'6	54'6	Basic norite	180'8	181'4	.50	.34	.84
177'6	252'4	74'10	Sulphides	181'4	184	.94	2.25	3.19
252'4	283'	30'8	Quartzite	184	188'8	.55	1.09	1.64
				188'8	191	4.39	.24	4.63
				191	194'10	2.59	None	2.59
				194'10	198	1.29	2.04	3.33
				198	201	.45	1.00	1.45
				201	206	2.09	.29	2.38
				206	207'4	2.70	.17	2.87
				207'4	212'4	.49	1.24	1.73
				212'4	213'8	.64	.34	.98
				213'8	216	2.83	None	2.83
				216	220	2.93	"	2.93
				220	225	1.95	1.70	3.65
				225	227'6	2.67	.33	3.00
				227'6	230	.95	.83	1.78
				230	234	1.06	.78	1.84
				234	239	2.24	.12	2.36
				240	241'6	.79	2.20	2.99
				241'6	245	2.32	.78	3.10
				245	250	.77	1.30	2.07
				250	252'4	2.24	1.00	3.24

[*E. J. Longyear Coy.*]

Certificate of Analysis of Composite Sample by Ledoux & Company, N.Y.

HOLE NO. 24, ANGLE 70°S.

Material after drying.	Per cent
Silica	27.85
Sulphur	17.08
Iron.....................	29.65
Arsenic.................	0.039
Copper	1.27
Nickel	1.79
Cobalt	0.14
Silver, per ton of 2,000 lbs.	1.00 oz.
Gold, per ton of 2,000 lbs.	0.21 oz.
Platinum, per ton of 2,000 lbs. (including platinum metals)...............	0.02 oz.

NOTE.—The platinum metals are too small in amount to be separated. They appear to be principally platinum.

(Signed) LEDOUX & CO.

NOTE.—Combined Copper and Nickel 3.06 per cent.

HOLE NO. 25, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	105′	105′	Surface........	105	140	.48	.28	.76
105	140	35	Norite with sulphides	155	155′6	2.78	Trace	2.78
140	148	8	Norite and quartzite mixed	169	171′2	1.02	.26	1.28
148	190′10	42′10	Ore and quartzite seams.	174	179	1.35	.22	1.57
190′10	221	30′2	Quartzite	179	180	1.93	.71	2.64
				180	180′8	.52	.68	1.20
				190	190′10	2.14	None	2.14

HOLE NO. 84, ANGLE 60°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	94′	94′	Surface	115′3	120	.47	.92	1.39
94	115′3	21′3	Norite with sulphides	120	125	2.17	·24	2.41
115′3	130′6	15′3	Norite and rich sulphides.	125	130′6	2.04	1.54	3.58
130′6	158′6	28′	Quartz					
158′6	164	5′6	Quartz and sulphides					
164	166	2′	Quartzite and sulphides...					
166	177	11	Quartzite					

[*E. J. Longyear Coy*]

HOLE NO. 85, ANGLE 80°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	132′	132′	Surface	132	135	.94	2.46	3.40
132′	149′	17′	Schist and ore	135	137	3.25	.74	3.99
149′	212′	63′	Schist and quartz	137	139′6	1.53	2.90	4.43
212′	239′	27′	Quartz	139′6	142	2.43	.84	3.27
				146′8	149	.98	6.10	7.08

HOLE NO. 86, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	140′	140′	Surface	171	176	.77	Trace	.77
140	190	50	Mineralized norite	176	178	.50	Trace	.50
190	194	4	Ore	178	181	.71	.30	1.01
194	199	5	Schist and quartz	181	185	....	.28	....
199	201	2	Ore	185	190	.71	.13	.84
201	229	28	Norite with sulphides	190	194	2.28	None	2.28
229	248	19	Schist..................	194	197	Trace	None	....
248	292	44	Quartzite-graywacké	197	199	.20	None	.20
				199	201	1.82	.46	2.28
				201	203	None	None	....

HOLE NO. 87, ANGLE 60°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	81′	81′	Surface	216	218	Trace	1.02	1.02
81	216	135	Norite................ ..	218	223	1.23	Trace	1.23
216	231	15	Mixed ore	223	228	.50	Trace	.50
231	269	38	Quartz	228	231	1.93	Trace	1.03

[*E. J. Longyear Coy.*]

HOLE NO. 114, ANGLE 60°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	149′	149′	Surface	244	245	.53	2.21	2.74
149	215	66	Norite with sulphides	245	248	2.89	None	2.89
215	244	29	Quartzite	249	250′9	3.25	None	3.25
244	248	4	Ore	254	256′6	3.11	None	3.11
248	249	1	Amphibolite dike	256′6	261′6	1.22	1.27	2.49
249	256′6	7′6	Ore and rock	264′6	269′6	1.14	1.64	2.78
256′6	275′10	19′4	Quartzite and sulphides ..	273	274′6	.50	2.09	2.59
275′10	294	18′2	Greenstone	274′6	275′10	Trace	1.22	1.22
				281′6	282′9	.61	.64	1.25
				282′9	284	2.39	.50	2.89
				284	285	.31	1.29	1.60

HOLE NO. 115, ANGLE 70°S. 23°E.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	125′	125′	Surface	125	127	2.43	1.05	3.48
125	127	2	Ore	138	140′6	2.10	.25	2.35
127	138	11	Greenstone with sulphides	143′6	146′6	Trace	.99	.99
138	140′6	2′6	Ore	146′6	150	2.90	.78	3.68
140′6	146′6	6′	Greenstone with sulphides	150	155	3.44	None	3.44
146′6	162′6	16	Ore	155	160	1.28	.41	1.69
162′6	177	14′6	Norite with sulphides....	160	162′6	3.06	None	3.06
177	177′8	8	Calcite with sulphides...	162′6	165	Trace	.56	.56
177′8	189′6	11′10	Norite with sulphides....					
189′6	190	6	Ore					
190	224	34	Greenstone					

HOLE NO. 133, ANGLE 70°S.-E.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	98′	98′	Surface	149′	151′	.79	1.57	2.36
98	136	38	Norite	151	154	.18	1.40	1.58
136	138	2	Schist....	160′10	162′10	.68	.69	1.37
138	149	11	Greenstone					
149	154	5	Greenstone with sulphides					
154	160′10	6′10	Greenstone					
160′10	162′10	2′	Greenstone with sulphides					
162′10	179	16′2	Greenstone					

[*E. J. Longyear Coy.*]

HOLE NO. 144, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	108′	108′	Surface	191′5	192′1	3.59	None	3.59
108	111	3	Basic norite	192′1	196	.944	.375	1.32
111	116	3	Micropegmatite	196	199	.894 cuttings	.197	1.09
116	191′5	75′5	Basic norite	203	211	1.61	.89	2.50
191′5	199	7′7	Sulphides and schist	209	210′6	1.38	1.94	3.32
199	209	10′	Quartz	212	213′9	.874	.394	1.27
209	210′6	1′6	Sulphides and schist	213′9	214′11	2.41	.629	3.04
210′6	212	1′6	Schist and quartz	214′11	216′5	.823	None	.823
212	216′11	4′11	Sulphides and schist	216′5	216′11	2.35	"	2.35
216′11	217′5	6	Schist	217′5	222	1.49	1.19	2.68
217′5	235′5	18′	Sulphides and schist	222	224′6	2.56	1.06	3.62
235′5	250	14′7	Quartzite and graywacké	224′6	226	1.20	.722	1.92
				226	231	2.10	.835	2.93
				231	233	2.29	Trace	2.29
				233	235′5	1.16	1.56	2.72

HOLE NO. 146, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	167′	167′	Surface	197	198′6	2.48	.25	2.73
167	197	30	Mineralized norite	217	220	.73	.79	1.52
197	198′6	1′6	Ore	220	222′6	3.98	None	3.98
198′6	209	10′6	Mineralized norite	222′6	226	.79	2.07	2.86
209	213	4′	Acid norite	226	231	.87	.16	1.03
213	217	4′	Mineralized norite	231	234	1.52	Trace	1.52
217	237	20′	Ore	234	237	1.83	.82	2.65
237	244	7′	Quartzite and graywacké	244	246	1.87	1.18	3.05
244	246	2′	Ore	246	247	.75	None	.75
246	248	2′	Mineralized quartzite and graywacké	247	248	1.03	.20	1.23
248	275	27′	Quartzite-graywacké					

[*E. J. Longyear Coy.*]

HOLE NO. 154, ANGLE VERTICAL.

Depth.		Thickness.	Material.	Assays.				
From ft. and inches	To ft. and inches	Ft. and inches		From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	48′	48′	Surface	50′6	51	1.81	None	1.81
48′	81′6	33′6	Graywacké with some ore	51′	52	2.62	"	2.62
81′6	100′6	19′	Quartzite with some ore..	52′	53	1.45	0.49	1.94
100′6	121′	20′6	Quartzite and graywacké	53′	56	Trace	.45	.45
121′	130′	9′	Quartzite and graywacké	56′	57	2.38	None	2.38
			with sulphides	57′	59′6	Trace	None	....
130′	249′	119′	Quartzite and graywacké.	59′6	60	1.30	.36	1.66
				60	61′6	1.28	None	1.28
				61′6	62′	1.96	4.17	6.13
				62	63	.33	Trace	.33
				63	64	1.78	1.46	3.24
				64	65	Trace	.28	.28
				65	66′6	1.08	2.63	3.71
				70	71	Trace	.23	.23
				71	71′6	.36	4.04	4.40
				79′6	80	2.76	None	2.76
				89	90	None	4.66	4.66
				91′6	94	1.88	Trace	1.88
				94	95	1.84	.89	2.73
				95	95′6	.41	.81	1.22
				95′6	97	1.73	.36	2.09
				97′6	98	.93	.02	.95
				99	100	.84	.62	1.46

HOLE NO. 155, ANGLE 70°S.

Depth.		Thickness.	Material.	Assays.				
From ft. and inches	To ft. and inches	Ft. and inches		From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	50′	50′	Surface	95′	100′	1.61	None	1.61
50′	52′	2′	Graywacké schist with sulphides.............	100′	104′	Trace	Trace	....
52′	58′	6′	Gray quartzite with sulphides	104′	110′	.53	.46	.99
58′	67′	9′	White quartzite					
67′	100′	33′	Schistose, quartzite and graywacké with sulphides					
100′	104′	4′	Clean quartzite					
104′	110′	6′	Schistose, graywacké with sulphides.............					
110′	150′	40′	Graywacké and quartzite					

[*E. J. Longyear Coy.*]

HOLE No. 156, ANGLE 60°S.

Depth. From ft. and inches	Depth. To ft. and inches	Thickness. Ft. and inches	Material.	Assays. From ft. and inches	Assays. To ft. and inches	Nickel	Copper	Comb. Metals.
0′	65′	65′	Surface	180′	182′	.97	None	.97
65′	80′	15′	Hornblendite	182′	183′	.71	0.56	1.27
80′	99′	19′	Basic norite with sulphides	183′	184′	.65	.76	1.41
99′	133′	34′	Micropegmatite..........	185′	188′	1.01	None	1.01
133′	155′	22′	Norite	191′ 6	192′ 6	1.39	"	1.39
155′	198′	43′	Graywacké with sulphides					
198′	201′	3′	Quartz					
201′	230′	29′	Graywacké with sulphides					

HOLE No. 159, ANGLE 60°S.

Depth. From ft. and inches	Depth. To ft. and inches	Thickness. Ft. and inches	Material.	Assays. From ft. and inches	Assays. To ft. and inches	Nickel	Copper	Comb. Metals.
0′	74′	74′	Surface	168	169	1.58	.44	2.02
74′	150′	76′	Norite	169	174	1.06	.64	1.70
150′	168′	18′	Mixed norite and graywacké	174	176′ 6	1.85	1.34	3.19
168′	179′ 6	11′ 6	Ore	176′ 6	177	2.03	1.49	3.52
179′ 6	181′	1′ 6	Graywacké with sulphides	177	177′ 6	2.69	.86	3.55
181′	187′ 6	7′ 6	Ore	177′ 6	178	1.54	.46	2.00
187′ 6	228′	40′ 6	Graywacké with sulphides	178	179	2.65	.75	3.40
228′	229′	1′	Quartz	179	179′ 6	2.09	.75	2.84
				181	184	2.88	.39	3.27
				184	186	2.15	.43	2.58
				186	186′ 6	1.16	.40	1.56
				186′ 6	187′ 6	1.27	.66	1.93
				187′ 6	188′ 6	.33	Trace	.33
				188′ 6	191′ 6	.89	.54	1.43
				198	199	Gold	None	....
				200	202	.47	.73	1.20
				205	207	.56	.15	.71
				207	208′ 6	1.10	.45	1.55
				208′ 6	211	.70	Trace	.70

[*E. J. Longyear Coy.*]

HOLE NO. 160, ANGLE 60°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0'	114	114'	Surface	208	210'6	.93	.27	1.20
114	156	42	Norite	210'6	211	1.80	Trace	1.80
156	177	21	Hornblendite	211	212'6	2.10	.31	2.41
177	192	15	Norite	212'6	215	1.31	.42	1.73
192	198	6	Chopped core	215	218'6	2.16	.31	2.47
198	199	1	Quartz	218'6	223'6	2.02	.60	2.62
199	208	9	Schist	223'6	227'6	1.55	.34	1.89
208	237	29	Schist and sulphides	227'6	228'6	.39	None	.39
237	263	26	Quartzite................	228'6	229'6	1.43	.26	1.69
				229'6	230'6	.70	.26	.96
				230'6	232	.34	.50	.84
				232'	233'6	.94	.34	1.28
				233'6	235'6	1.20	.51	1.71
				235'6	237	.61	.45	1.06

HOLE NO. 193, ANGLE 60°N.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0'	74'	74'	Surface	297'	300'	.86	.92	1.78
74'	297'	223'	Graywacké and quartzite.	300	305	.85	None	.85
297'	312'	15'	Sulphides and schist	305	307	1.41	"	1.41
312'	315'	3'	Schist with sulphides	307	308'6	.79	.63	1.42
315'	345'	30'	Norite..................	308'6	310'	1.35	1.21	2.56
				310	310'10	2.43	None	2.43
				310'10	312	1.39	.19	1.58

HOLE NO. 302, ANGLE VERTICAL.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0'	58'	58	Surface	60'	65'	.73	1.48	2.21
58	88	30	Norite with sulphides ...	65	70	.46	2.72	3.18
88	129	41	Mixed norite and graywacké with sulphides..	70	73	.44	1.58	2.02
129	165	36	Graywacké	73	78	.63	2.08	2.71
				78	83	.35	2.32	2.67
				83	88	1.08	.66	1.74
				88	93	2.88	.73	3.61
				93	95'6	2.34	.26	2.60
				95'6	100'6	.33	1.26	1.59
				100'6	104	.55	2.84	3.39
				104	109	.96	3.46	4.42
				109	111'6	.31	1.76	2.07
				111'6	114	3.59	.08	3.67
				114	114'6	1.09	.55	1.64
				114'6	119	3.15	.59	3.74
				119	124	2.91	.08	2.99
				124	129	2.71	None	2.71

[*E. J. Longyear Coy.*]

HOLE NO. 303, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	85′	85′	Surface	120	122′6	1.61	.54	2.15
85	120	35	Norite and sulphides.....	122′6	123	3.50	None	3.50
120	219′5	99′5	Rich sulphides and schist	123	124	.57	"	.57
219′5	248	28′7	Quartzite and graywacké.	124	125′3	3.22	Trace	3.22
				125′3	126′9	1.90	None	1.90
				126′9	127′4	1.92	.15	2.07
				127′4	131	3.01	.17	3.18
				131	132′8	.86	1.41	2.27
				132′8	133′9	1.83	15.63	17.46
				133′9	135	2.10	3.44	5.54
				135	136′10	1.61	None	1.61
				136′10	137′6	3.50	"	3.50
				137′6	141	2.16	1.42	3.58
				141	142	3.50	None	3.50
				142	143′6	3.52	.45	3.97
				143′6	148	3.01	None	3.01
				148	148′9	1.63	1.58	3.21
				148′9	153′9	2.43	3.60	6.03
				153′9	158′9	2.94	.42	3.36
				158′9	160′10	3.52	.55	4.07
				160′10	161′4	.65	None	.65
				161′4	163′4	3.87	"	3.87
				163′4	165	1.05	2.46	3.51
				165′	166′6	4.12	None	4.12
				166′6	169′6	1.03	.18	1.21
				169′6	174′6	3.45	None	3.45
				174′6	176′6	3.65	.31	3.96
				176′6	178	2.03	1.28	3.31
				178	180	3.13	None	3.13
				180	185	3.12	.08	3.20
				185	190	3.91	None	3.91
				190	195	3.04	.69	3.73
				195	200	2.24	.13	2.37
				200	205	1.96	2.86	4.82
				205	210	3.72	.80	4.52
				210	211′3	2.82	.22	3.04
				211′3	215′8	3.88	.92	4.80
				217′3	219′5	1.08	None	1.08

Certificate of Analysis of Composite Sample by Ledoux & Company, N.Y.

HOLE NO. 303, ANGLE 70°S.

Material After Drying.	Percent.
Silica	20.37
Sulphur	21.49
Iron	35.40
Arsenic...................	0.125
Copper	1.20
Nickel	2.57
Cobalt	0.25
Silver (per ton of 2000 lbs.)	Trace
Gold (per ton of 2000 lbs.)	0.03 oz.
Platinum (per ton of 2000 lbs.) including platinum metals	0.01 ozs.

NOTE:—The platinum metals are too small in amount to be separated. They appear to be principally platinum.

(Signed) LEDOUX & CO.

NOTE:—Combined Copper and Nickel 3.77 per cent.

[*E. J. Longyear Coy.*]

HOLE NO. 304, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	83′	83′	Surface..................	111	116	.62	.32	.94
83′	128′	45′	Norite with sulphides ...	128	131	4.02	.54	4.56
128′	203′	75′	Ore......................	131	134	3.58	None	3.58
203′	336′	133′	Quartzite and graywacké	134	136	.59	1.86	2.45
				136	137′4	2.18	6.07	8.25
				137′4	138′6	1.94	4.57	6.51
				138′6	140′4	3.59	.48	4.07
				140′4	144	3.34	.53	3.87
				144	147′6	2.26	3.41	5.67
				147′6	151	1.60	1.86	8.46
				151	152′2	2.50	.66	3.16
				152′2	153′8	4.58	.76	5.34
				153′8	155′4	2.67	.46	3.13
				155′4	156′10	3.59	.38	3.97
				156′10	161′10	3.02	.46	3.48
				161′10	166′10	1.33	2.12	3.45
				166′10	168′6	.80	2.07	2.87
				168′6	173′6	2.64	1.43	4.07
				173′6	177	.77	2.56	3.33
				177	178	3.01	1.50	4.51
				178	179′6	2.65	1.38	4.03
				179′6	181′4	2.03	None	2.03
				181′4	184	2.83	1.10	3.93
				184	185′6	3.97	.76	4.73
				185′6	188	2.84	None	2.84
				188	192	4.23	None	4.23
				192	194′10	4.15	None	4.15
				196′6	199′3	2.72	None	2.72
				199′3	203	1.47	None	1.47

HOLE NO. 306, ANGLE 70°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0′	65′	65′	Surface..................	66	93	.43	.60	1.03
65′	93′	28′	Norite with sulphides	104	121	.45	.31	.76
93′	101′	8′	Granite..................	121	126	.52	1.04	1.56
101′	104′	3′	Norite and granite mixed	126	130	.79	1.08	1.87
104′	130′	26′	Norite with sulphides	130	131	1.88	3.77	5.65
130′	142′	12′	Ore......................	131	135	1.64	2.39	4.03
142′	147′	5′	Igneous schist	135	140	3.93	.83	4.76
147	156′	9′	Ore......................	140	142	4.02	.71	4.73
156′	160′6	4′6	Schist...................	147	152	3.72	.62	4.34
160′6	163′10	3′4	Ore......................	152	156	.71	1.76	2.47
163′10	165	1′2	Quartzite................	160′6	163′10	2.41	2.46	4.87
165	167′6	2′6	Ore......................	165	167′6	2.36	1.20	3.56
167′6	195	27′6	Quartzite with sulphides.	181′6	186′6	.26	.33	.59

[*E. J. Longyear Coy.*]

HOLE NO 307, ANGLE 75°S.

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
0'	100'	100'	Surface..................	100'	139'	.45	None	.45
100	124	24	Norite with sulphides....	139	141'9	1.87	1.27	3.14
124	127	3	Granite..................	146	149'4	1.77	.88	2.65
127	146	19	Norite with sulphides...	149'4	151	3.72	None	3.72
146	273	127	Ore......................	151	152	2.80	Trace	2.80
273	283	10	Mineralized quartzite	152	157	3.72	None	3.72
283	342	59	Ore......................	157	162	3.27	None	3.27
342	441'6	99'6	Mineralized norite	162	162'6	3.12	None	3.12
441'6	447	5'6	Ore......................	162'6	164	1.37	Trace	1.37
447	525'10	78'10	Mineralized norite	164	169	1.34	1.36	2.70
525'10	582	56'2	Ore......................	169	171	1.09	.90	1.99
582	627	45	Quartzite................	171	174	1.15	.44	1.59
				174	179	2.23	.17	2.40
				179	184	2.25	.39	2.64
				184	187	1.14	.66	1.80
				187	189	2.34	.39	2.73
				189	193	1.38	None	1.38
				193	194'9	2.85	.42	3.27
				194'9	196	1.37	.37	1.74
				196	199	3.84	.43	4.27
				199	204	3.47	.75	4.22
				204	209	2.87	.34	3.21
				209	214	3.26	.56	3.82
				214	219	3.98	.27	4.25
				219	224	3.63	None	3.63
				224	229	1.03	.64	1.67
				229	234	1.65	2.10	3.75
				234	239	2.57	.48	3.05
				239	241	3.34	.59	3.93
				241	243	1.29	.30	1.59
				243	245	2.55	.20	2.75
				245	248'6	3.39	None	3.39
				248'6	252	3.63	.36	3.99
				252	257	2.56	.86	3.42
				257	258	.81	Trace	.81
				258	263	2.78	.34	3.12
				263	268	2.32	2.18	4.50
				268	271	.42	.78	1.20
				271	273	2.65	3.30	5.95
				273	278	.45	Trace	.45
				278	283	Trace	.21	.21
				283	287'6	1.69	2.85	4.54
				287'6	291	2.24	1.80	4.04
				291	294	3.36	.53	3.89
				294	296'4	.92	2.26	3.18
				296'4	301	2.90	Trace	2.90
				301	306	3.24	.68	3.92
				306	311	2.97	Trace	2.97
				311	316	3.35	.57	3.92
				316	321	3.15	.41	3.56
				321	323'6	3.51	None	3.51
				323'6	324'6	1.18	None	1.18
				324'6	327	3.23	1.26	4.49
				327	330	1.86	.75	2.61
				330	331'6	3.28	.29	3.57
				331'6	332	.38	None	.38
				332	335'6	3.24	None	3.24
				335'6	336'4	.94	Trace	.94
				336'4	339'8	2.89	Trace	2.89
				339'8	342	1.02	.24	1.26
				440	441'6	.32	None	.32
				441'6	444	1.65	None	1.65

[*E. J. Longyear Coy.*]

HOLE NO. 307, ANGLE 75°S.—*Continued.*

Depth.		Thickness. Ft. and inches	Material.	Assays.				
From ft. and inches	To ft. and inches			From ft. and inches	To ft. and inches	Nickel	Copper	Comb. Metals.
				444	447	.83	1.52	2.35
				522	524	.98	1.02	2.00
				524	525′10	1.88	.37	2.25
				525′10	529	4.00	None	4.00
				529	534	1.67	1.34	3.01
				534	540	1.29	Trace	1.29
				540	544	2.27	2.78	3.05
				544	549	2.03	.40	2.43
				549	554	2.99	None	2.99
				554	559	2.92	None	2.92
				559	563′6	2.19	None	2.19
				563′6	568	2.34	None	2.34
				568	571	2.53	None	2.53
				571	574	2.51	Trace	2.51
				574	577	2.62	.12	2.74
				577	580	.68	None	.68
				580	582	3.34	Trace	3.34
				582	587	.31	Trace	.31

[*E. J. Longyear Coy.*]

HOLE No. 308, ANGLE 70°S.

Depth. From ft. and inches	Depth. To ft. and inches	Thickness. Ft. and inches	Material.	Assays. From ft. and inches	Assays. To ft. and inches	Nickel	Copper	Comb. Metals.
0′	134′	134′	Surface	138	166	.36	None	.36
				166	168	.12	Trace	.12
134	146	12	Granite and some norite..	168	169	.56	1.17	1.73
				169	173	3.09	None	3.09
				173	178	3.31	Trace	3.31
146	155	9	Mineralized norite........	178	178.6	.22	None	.22
				178′6	182	2.76	.40	3.16
155	169	14	Mineralized quartzite	182	183	3.54	.15	3.69
				183	185′4	3.36	None	3.36
				185′4	187′3	.96	None	.96
169	254	85	Ore	187′3	189′3	3.23	None	3.23
				189′3	191	1.15	3.59	4.74
254	268	14	Quartzite................	191	193	2.67	None	2.67
				193	198	3.38	None	3.38
268	281	13	Ore	198	203	2.80	None	2.80
				203	208	3.13	None	3.13
281	286′6	5′6	Quartzite................	208	213	2.74	None	2.74
				213	216′6	1.95	None	1.95
286′6	308′3	21′9	Mixed ore and rock......	216′6	217′6	.79	1.66	2.45
				217′6	220	3.04	None	3.04
308′3	324′6	16′3	Quartzite	220	224′6	.81	1.31	2.12
				224′6	227	3.88	None	3.88
324′6	327	2′6	Ore	227	230′4	3.12	None	3.12
				230′4	233	3.78	None	3.78
327	359	32	Quartzite	233	238	2.62	.41	3.03
				238	242′6	2.34	.40	2.74
				242′6	244′6	.935	.28	1.215
				244′6	247′6	3.57	Trace	3.57
				247′6	254	2.47	1.15	3.62
				254	256	.22	Trace	.22
				268	270′6	3.04	.37	3.41
				270′6	271	3.60	None	3.60
				271	276	3.33	None	3.33
				276	281	.80	.45	1.25
				286′6	290	3.47	None	3.47
				290	295	3.30	3.27	6.57
				295	298′4	3.58	.12	3.70
				298′4	300	Trace	None	....
				300	301′5	3.07	None	3.07
				301′5	302	.37	None	.37
				302	302′9	3.24	None	3.24
				302′9	304′6	2.78	None	2.78
				304′6	306	3.65	.42	4.07
				306′	307′6	.24	None	.24
				307′6	308′3	2.68	1.86	4.54
				308′3	310′3	Trace	None	....
				322′6	324′6	Trace	.33	.33
				324′6	327	3.72	1.09	4.81
				327	329	.39	.39	.78

[*E. J. Longyear Coy.*]

HOLE NO. 309, ANGLE 70°S.

(Incomplete)

Depth. From ft. and inches	Depth. To ft. and inches	Thickness. Ft. and inches	Material.	Assays. From ft. and inches	Assays. To ft. and inches	Nickel	Copper	Comb. Metals.
0′	147′	147′	Surface	147′	155′	1.85	.33	2.18
147	230	83	Sulphides	155	158′6	2.50	.55	3.05
				158′6	163	Trace	Trace	....
				163	166′2	1.77	Trace	1.77
				166′2	171	2.15	.23	2.38
				171	176	3.10	None	3.10
				176	181	3.05	None	3.05
				181	183	3.83	None	3.83
				183	188	2.55	.52	3.07
				188	193	2.27	None	2.27
				193	198	2.59	1.11	3.70
				198	201′6	2.37	Trace	2.37
				201′6	203	.45	None	.45
				203	208	1.45	Trace	1.45
				208	211	2.56	.66	3.22
				211	213	1.54	.61	2.15
				213	217	2.48	1.08	3.56
				217	222	2.49	.20	2.69
				222	226	1.87	.22	2.09
				226	230	2.05	1.79	3.84

HOLE NO. 310, ANGLE 70°S.

(Incomplete)

Depth. From ft. and inches	Depth. To ft. and inches	Thickness. Ft. and inches	Material.	Assays. From ft. and inches	Assays. To ft. and inches	Nickel	Copper	Comb. Metals.
0′	112′	112′	Surface	145′	147′	1.08	Trace	1.08
112	145	33	Norite	147	152	2.73	.79	3.52
145	160	15	Sulphides................	152	153′4	.47	.69	1.16
				153′4	155	.79	2.14	2.93
				155	160	1.43	.84	2.27

[*E. J. Longyear Coy.*]

SECTION N

TAXATION OF MINES

EVIDENCE AT SUDBURY, 25TH SEPTEMBER, 1916

Mr. Thomas Travers, Diamond Drilling Contractor, Mayor of Sudbury

CHAIRMAN: Is there any other matter in connection with our enquiry, Mr. Travers, such as refining or taxation, that you care to express any view upon? A. Well, there is the question of taxation. I think that ore, perhaps at the mouth of the pit, should be taxed. My opinion is that if ore developed in the ground were taxed, it would stop the development of the country; suppose there was a 5 per cent. tax put on developed ore, in a few years it would eat up the value of the ore; it would stop the people developing their properties; whereas, if the ore was assessed as it came out of the ground, at the mouth of the pit, that would be the better way.

MR. GIBSON: Have you any knowledge of taxation methods in Michigan and Minnesota, in the iron fields there? A. No. During my experience there they had not got so far as taxing the ore. I have been here in Canada for twenty-five years.

Q. Are you aware that in Michigan and Minnesota they do actually assess the ore in the mine? A. Yes, I know that.

Q. They make a valuation? A. Yes, of the ore in the mine.

Q. And tax upon that valuation? A. Yes.

Q. What is your view of that system of taxation? A. I don't like that system of taxation at all. I think it is a disadvantage to the district. I think it stops development.

Q. Do you think that a company having a deposit of ore would not for its own purposes, to enable it to develop the ore body properly and lay its plans for future working, go on and develop the ore, notwithstanding the taxation? A. I don't think they would; they would develop the properties that were for immediate use. It would in any event, be a severe hardship. Anyone starting a mine wants first of all to find out what amount of ore he has in order to mine it economically. Now, if he had to pay taxes on the ore as he developed it in the mine, it might not stop him developing, but I think it would be a severe hardship to pay up for the ore that he wouldn't use for ten or fifteen years. By the time he used that ore, it would have cost him more than it was worth.

Q. You think it would not only check development, but it might embarrass proper mining operations? A. Yes, and it would check development.

Q. Then, have you considered the merits of such a system of assessment and taxation in comparison with the one at present in vogue in Ontario? Have you given that matter any thought? A. No, I have not.

Q. The taxation at present in Ontario is on the net profits? A. Well, I think that is a very fair way of taxing.

Q. Have you any objection to the present system? A. Not at all, but I wish to get away from the possibility of taxing ore in the ground.

Q. It is sometimes argued that a company which owns a large undeveloped mine has a valuable property, just as a man who has a large farm, who could sell it if he wished. Why should not the mine be assessed and taxed just the same as the farm? A. Many ore bodies in the district have not yet been worked for some reason or other. I always thought it was because there was not a market for the nickel, or because it took too much capital to start operations. Now, if the owners could not make use of that ore in the ground, it would be a hardship to them to pay taxes on it. When there was a market they could sell it, even the holders of big property. As soon as ever there was a good market some of the companies would want to use the properties.

Q. In other words, there is no value unless there is a prospective sale at a profit? A. No.

MR. YOUNG: Have you given any thought at all to the relation of the municipality to the Provincial tax? A. No, I have not.

Mr. J. F. Black, Mine Owner, Sudbury

CHAIRMAN: What about taxation, Mr. Black? A. I think the present method, a tax on the net profits, is a good one if properly carried out. To tax the ore at the pit's mouth so much per unit, would be a good method, deducting all expenses, mining explosives and so forth. I think either method is a good one. I would be very much opposed to taxing the ore

in the ground; I think it would retard development. I think it would be a hardship in some cases. Suppose a prospector gave an option on a property—prospectors are not generally very wealthy men—the company taking the option might develop say half a million tons of ore, or a hundred thousand tons of ore, and let the option lapse. Well, if the government stepped in and taxed the ore in the ground, the chances are they would tax the property out of the possession of the owner; he would not be able to pay. It is exceedingly hard for many prospectors to comply with the present mining regulations. It costs a man from $1,000 to $1,500 for a forty-acre claim before he can get the deed. This prospectors really consider a great hardship, and I have no doubt in the world that it has had the effect of retarding prospecting in the district. I know dozens of men who say they cannot afford to go into the woods on account of the excessive cost of owning a forty-acre claim; so to load any more on top of that would be, I think, next to suicide.

MR. YOUNG: Some of the advocates of taxing in the ground would make it an exception in the case of the prospector; the first purchaser would cover the cost you mention. It is only fair to that system of taxation to say that they consider that phase of the case? A. But outside of that, I think it would retard the development of the district.

Q. And I suppose there is an element of conjecture in estimating the tonnage of a mine? A. Yes. I think there have been instances in the district where diamond drilling has shown ore to exist and on working the body there was not as much there as had been figured out, and *vice versa*. I think the North Star mine was one instance. I would not be positive on that point.

MR. GIBSON: Was there more or less ore found in the North Star than was expected? A. I think less, from all the information that I have had on that point.

MR. YOUNG: I gather from you that you prefer some net system, making allowances for proper expenditures in mining? A. Yes; the present system is a good system if it was properly carried out.

MR. GIBSON: You say if it was properly carried out, Mr. Black. Have you any criticism to offer on that point? A. Yes. I am on record already on that point. If the law were carried out, the tax to the Province of Ontario should be increased very largely. One company in the district is paying about $40,000. If it were taxed according to the Act, it would be paying very much more.

Q. What is your idea of the basis of taxation that is contained in the Act? A. Well, the Act states that all profits are taxable over $10,000.

Q. Isn't that based on the value of the ore at the pit's mouth? A. It might be, yes.

Q. Doesn't the Act state so? A. Well, the Act does say, that "the annual profits shall "be ascertained and fixed in the following manner, that is to say:—The gross receipts for the "year's output of the mine, or in case the ore, mineral, or mineral-bearing substance or any "part thereof is not sold but is treated by or for the owners, tenant, holder, lessee, occupier "or operator of the mine upon the premises or elsewhere, then the actual market value of the "output, at the pit's mouth, or if there is no means of ascertaining the market value, or if "there is no established price or value, the value of the same as appraised by the Mine "Assessor, shall be ascertained, and from the amount so ascertained the following, and no "other expenses, payments, allowances or deductions shall be deducted or made, etc." (See section 6 of the Mining Tax Act.) I notice the Dominion and Provincial governments give the value of the ore, or at least, the matte going out of the country at so much, but if it were figured at the market value, it is worth at least three times as much.

Q. You are aware, of course, that the matte is not subject to taxation? A. I am aware of that, but the value of the ore is really contained in the matte.

Q. But under the Act the capital and labour expended on the further treatment of the ore is not considered to be subject to taxation? A. No.

Q. So far as the Act is concerned then, it is fairly carried out? A. Well, it all depends on how you look at it.

Mr. W. E. Smith, Mining Prospector, Sudbury

CHAIRMAN: Will you begin by giving us an account, Mr. Smith, of your connection with the industry? A. I have not had any intimate association or connection with the operating nickel companies. I have been exploring for mineral properties in northern Ontario for thirteen years, not alone in nickel but every other metal as well, and what I can say is largely to reiterate what Mr. Travers and Mr. Black have said with regard to the question of deposits. I am in accord with them, too, in the taxation proposition; that it should be on net profits, and not on the ore blocked out in the ground. I believe it has been computed in Minnesota and Michigan, where these systems of taxing are in force, that it would not pay to block out iron ore where it would only run 45 per cent. metallic iron, for the reason that by the time ore of that grade is useable, as it probably will be some time, the property would be taxed to such an extent that there would be no value to the owner. Such a system of taxation is very hard on exploration companies. On the

Mesabi range where there were twenty diamond drills operating prior to that law coming into force, there is only one now. The companies are only blocking out the ore that they need in their actual mining operations. The reserves of the country are not developed to the extent that they would be with a tax on net profits.

MR. YOUNG: You are a mining engineer, aren't you, Mr. Smith? A. No, I am not. I am a prospector. I have some technical training, but I have not the engineering degree.

Q. Are you familiar with the conditions in Minnesota and Michigan? A. Not intimately. I have some general information in regard to conditions over there.

MR. GIBSON: If a person has a property which he can sell, there is value there, is there not? A. Yes.

Q. And aren't values anywhere proper subjects for taxation? A. Well, if it is a farm there is generally some income derived from the property, but a mine is of such a nature that unless it is operating there is no value derived.

Q. Aren't many industries taxed without any reference at all to the profit produced? A. Take a large acreage of wild lands; they are valuable, but they are not taxed according to that value. They may have value, but you cannot dispose of the property, and there is no income from it. In the case of a farm or mercantile business there is an income, but with a mine there is no possibility of income from it until the ore is mined.

Q. But if the element of value exists; that element is there, and the basis of taxation is value? A. Yes.

Q. What can you say in favour of exempting a mine, even if it be undeveloped, under that general rule? A. I would not exempt it from an acreage tax.

Q. But the acreage tax has no reference to its value. A tract of wild land may be of no value, and pay the same as a large body of mineral? A. Well, of course, your point is good, but it appeals to me that the avoidance of retarding the exploration and development of a district would perhaps make for a system of taxation satisfactory to all concerned.

Q. I am not arguing in favour of the ad valorem system, but I am bringing out that point? A. Yes, I see your point.

MR. YOUNG: What is the best system of taxation to consider for the prospector? He is not the only person to be considered, but he is one and a very material one? A. Of course, the prospector hasn't very much ore blocked out. By the time the ore is blocked out, he has generally disposed of his property, except in such a case as Mr. Black brought out, where the property has been optioned and come back on his hands. That didn't occur to me until this morning, but I think it would be severe on the prospector in a case of that kind.

MR. GIBSON: It would be severe if he was a poor man? A. Yes.

Q. It would not be severe if he were a rich man? A. No.

MR. YOUNG: Take the case of the prospector where there is no ore blocked out. Suppose a prospector has the good fortune to locate a good property, where the conditions indicate value; then the assessor comes along and says: "We think from these indications you have got a mine that is worth half a million dollars." The point is, why shouldn't he be taxed? A. If he were a prospector and it could be demonstrated it was worth half a million, I think he would be glad to take it.

Q. Then, wouldn't it have the advantage of facilitating development? A. It might bring possible buyers to his property. It might have an effect in that way.

Q. But there are those who keep properties designedly undeveloped. It is perfectly legitimate to hold reserves of ore for future use? A. Yes.

Q. But so long as these bodies are kept out of use they are not subject to taxation. Have you anything to say about that? Is that fair? A. Well, it would depend largely whether the property was in demand. If a mining company were operating and had sufficient ore, and were paying taxes on the net profits, the fact that they had a few million tons in reserve is really of no value to them until the time that they start to mine that ore.

Q. You can hardly say it is of no value to them? A. No, but they are not deriving any profit from it.

Q. Do you think the prospectors want any change in the system of taxation? A. No, I don't.

Q. How about the two cents per acre tax? A. I think two cents is very low.

Q. You think that could be raised to advantage? A. Yes.

Q. Have you considered to what extent? A. I think it could be at least doubled, and still be a low tax.

Q. What would be the advantage of that? A. Just to produce a revenue; of course there is no taxation until the property is patented

Q. And then only two cents an acre until it is developed and begins to produce profits? A. Yes

[*W. E. Smith.*]

Mr. J. A. Holmes, Mining Engineer, Sudbury

MR. GIBSON: On the ad valorem system of taxation, Mr. Holmes, the additional ore in a mine beyond reasonable requirements for operating it, would remain undeveloped? A. I am positive of it, because it has been tried. I have a number of friends in Minnesota who were formerly in the exploration business; they owned mineral lands, and as they got their royalties out of their properties they went ahead, and proved up more ore. To-day they are sitting back and taking their royalties, and won't develop any more ore for years to come.

Q. Is that due to taxation? A. Due to the taxation, yes.

Q. The taxation in Michigan is pretty heavy? A. Yes, they soak them pretty hard over there. Michigan, as you know, consists of two peninsulas. The southern peninsula is largely farming and manufacturing; in the northern the principal industries are mining and lumbering. They have not a great deal in common, and the farmers and manufacturers in southern Michigan don't see why these rich land owners in northern Michigan should not contribute largely to the expenses of running the government.

MR. YOUNG: These conditions were explained to us by the local officials. A. A great many people that were formerly in the development business and put their money in the developing of lands, simply stopped.

MR. GIBSON: Have you given the question of taxation outside of that, much consideration? A. No, I have not. I have always felt that the system of taxing a company on its net profits was a fair one to all concerned. It gives the little fellow a chance to get started. It gives the prospector a chance, and I don't think any of the companies ever object to paying their fair share of taxation. I don't think any honest individual would. They are all willing to pay their fair share. It is only a question of ascertaining what that share is.

Mr. James Purvis, Merchant, Sudbury

MR. GIBSON: We were told, Mr. Purvis, that you were a man of good common sense with considerable experience in business. We thought it would be useful to get the views of a man of that kind? A. In regard to mining matters, I certainly have my views, like any other intelligent man.

Q. Well, we would be pleased to have them. A. I think that governments make a tremendous mistake when they part with the patrimony of the people, mines amongst the rest. The mines pass out of their ownership; then they are developed, and it is discovered all at once in some instances that they are very valuable. The people, myself and others, think that we are not getting our share of the wealth that we are entitled to. Well, there are two ways of looking at that. First, I suppose, from what I read, there is hardly any business so risky as mining. Let it be any kind of mining, the disappointments are many and rewards very few. In theory I am in favour of government ownership; but the next thing is, how would we ever get the mines developed under government ownership? Could the government be prospectors, or would they be? There is not the same force in the government developing a thing that there is with private ownership, so that possibly we get back to pretty nearly where we are. In regard to water powers, lands and timber, matters are different. We have got practical men and scientific men who could really give us approximate values in mines; notwithstanding this and all the magnetic surveys and diamond drillings, the value is problematical still. Seeing that the mines have been parted with by the government, the taxation should be, I think, only after a reasonable dividend is paid; as to mines that are not developed, I do not see how in fairness you are going to tax them. If you tax the man not able to pay, the prospector or discoverer, the tax will pile up, and he would simply forfeit his right. He should be protected. I don't know that I can tell you anything but what you know at the present time.

Q. You have had some experience in municipal life, Mr. Purvis? A. Yes.

Q. Have you studied the working of the present Ontario Mining Tax Act? A. No, I have not.

Mr. James R. Gordon, Mining Engineer, Sudbury

CHAIRMAN: What are your views regarding the taxation of mines, Major Gordon? A. I think the present law with some few changes is satisfactory, and if it were not satisfactory, radical changes would do the industry more harm than an inferior law.

Q. Have you compared the Ontario taxation laws with those of other countries? A. Yes, for instance, the California law and the British Columbia law; but the most up-to-date in reference to the taxation is the California law, which is on the net profits. They have a system which necessitates elaborate bookkeeping and cross entries and all that sort of thing; practically a public utility, and they keep a special man to keep up the records, and if any question arises an auditor is sent at the expense of the government to look

[*J. A. Holmes; J. Purvis; J. R. Gordon.*]

into the books. It is a very elaborate system. In other places taxation has sometimes been tried on the properties. In one case it was fought out on the valuation of the property which it is practically impossible to make; another was with reference to the transfer of properties, and it was found that it absolutely killed all prospecting and all development work.

MR. GIBSON: What would you say with regard to the merits of the Ontario system as compared with those you have mentioned? A. I think it is a most satisfactory system, with some changes.

MR. YOUNG: What are those changes? A. To put the poor property with a small output on an equal basis with the wealthy company, allow them to charge up powder, and anything that can be fairly traced through the books.

MR. GIBSON: Of course, you are aware that all such charges as powder, labour and fuel now are allowed? A. Yes, I knew that, but I didn't think they allowed anything for depreciation, which I think a small company would need.

Q. Depreciation of what? A. Machinery.

Q. Oh, yes, that is allowed. A. Well, I had forgotten that.

Q. Everything is allowed for, except exhaustion of the mine and dividends. A. Oh, well, that is perfectly satisfactory. I have been away for some years, you know.

MR. YOUNG: That would remove your objections? A. Yes.

MR. GIBSON: In your opinion, is it possible to value a mine satisfactorily for assessment and taxation purposes? A. No, I don't think it could be done at all. As a sample, the Murray mine was developed by the Swansea people. They spent a large amount of money here and put up a plant, and abandoned the mine because it did not pay. To-day that has proved to be a valuable property, simply because they got high grade ore at depth.

MR. YOUNG: If I retained you to advise me on the purchase of a mining property, would you not give me the value? A. No. If you give me the option price of it, what I would say to you would be, "Well, the surroundings look favourable. I would suggest that you do development work under option. Drop it, if that development work does not turn out satisfactorily."

Q. Should not a mining engineer be able to give a fair idea of the extent and value of the ore deposit? A. He may have an idea, but he has nothing that he could put on paper and say it was a fair value, and he couldn't suggest to his principal anything but development.

Q. Well, do you think the State would be in the same position with its experts? A. I think so, only worse.

Q. The general impression in mining circles is that the ad valorem assessment has a tendency to check development seriously; not merely to check it in a trivial way, but to hamper the mining industry. Would you agree with that? A. I think it is more imaginative than otherwise. Some time ago there was a move on in this district. A good many properties were up for sale. I knew of three or four cases myself, and the question of royalties came up and killed this district absolutely dead for the time being. The royalties weren't any particular detriment, but they frightened capital. That is the only way it might do any harm.

Q. You say, in your opinion, the valuation of mines is not very practicable? A. It is not practicable at all.

Q. Would you draw any distinction between large bodies of ore such as iron mines or nickel mines, and other mineral deposits which are more irregular, such as gold and silver? A. Well, you can only judge by the surroundings and the character of the country as already developed or known. For instance, I offered a large concern the properties that are now known as the Moose Mountain iron mine, consisting at that time of five lots, for $16,000, and the offer was turned down, simply because two experts went, one from Denver and one from Chicago, and pronounced the deposit flat, and they asked for time for development and could not get it. Now, there was a property with a 900-foot showing, and it looked like a good thing. I said it was worth a million, and this opinion has proved to be correct by later development. So I don't think you can judge except from development. For instance, take the property at Creighton. They are working pretty close to another man's land, and it might be safe to say if you wanted to purchase the adjoining property, you could use the Creighton for development. That has been done, but where there is no development I don't think it could be done.

Q. But in those States in which the mine is valued, the valuation is made upon borings and other data that the companies themselves have obtained? A. They find it themselves, and don't give it to the general public.

Q. No; but the government gets it? A. Well, what would be the consequence? If I owned a group of properties, and I was working one and had ore enough in sight for the next few years, I wouldn't do any further development. I would say, "We will wait until this government changes, and perhaps get a better chance next time."

Q. Your idea would be that taxation of that kind would greatly retard development? A. I think so.

Q. And that would apply to veins containing gold and silver as well as to large masses of ore? A. Probably more, because while you may have a good idea of large

[*J. R. Gordon.*]

bodies of ore from the country adjoining, smaller ones might pinch at any stage, and you wouldn't know.

MR. GIBSON: What about the acreage tax? A. It depends on what basis.

Q. The present acreage tax of two cents an acre? A. Well, there are some properties up here on the lake that I examined and reported upon for the Krupp people sixteen years ago, and the man that owned them didn't make a sale, and even that two cents an acre caused those properties to be forfeited. They were re-staked and are offered for sale to-day at a very much reduced rate. That property is not working. There is no chance for development. Taxation which would be worth while would cause properties to fall into the hands of the big companies that could afford to pay the taxes.

Mr. Lawrence O'Connor, Merchant, and ex-Mayor of Sudbury

CHAIRMAN: With regard to the question of taxation, Mr. O'Connor, have you any views on that subject? A. I think the nickel mining industry should not be taxed at all. Personally, I think that the expenditure of money by the nickel companies in this district is sufficient for the Province without any direct tax. I think they are paying a good enough tax. That is my personal view on the matter.

MR. GIBSON: You pay taxes, Mr. O'Connor? A. I certainly do.

Q. Do you think it would be fair to relieve any particular portion of the community of its just proportion of the public burdens? A. I don't think any mining company should be exempt from any municipal tax, but I think that companies that are developing this particular section of the country should not be called upon to pay the government a tax over and above that; I think the mining business is a huge gamble to a certain degree, and the man that puts his money into it and makes a success of it, is deserving of the support of the general public.

Q. If the public lands are the property of the public, and part of them containing very valuable deposits of mineral passes into the possession of an individual or a company at a nominal figure—nothing at all approaching the value of it—would you regard that as a reason why that individual or company should be called upon to contribute a share towards the public revenue? A. No, I would not. A man comes up here and is fortunate enough to strike a mine; he develops it; he employs the labour of this Province; he buys his goods from the merchants and manufacturers of the older parts; he has to bring his supplies in here for years (except in the last few years when the farmers in this country have supplied him); he is spending his money in developing this country, and the older part of the Province is getting the benefit of it.

MR. YOUNG: It would be a comforting doctrine for the railroads? A. I know. You take the money orders that we have sent out of here for the last twenty-five years to Toronto. You would think it was a good thing for the city of Toronto that the nickel development was going on up here, but they don't seem to bother much about it.

Q. Presumably those who bought goods in Toronto or elsewhere got value for their money? A. Certainly they did, but if this nickel industry hadn't gone on up here they wouldn't have got it.

Q. That touches a very much larger question; the railroads, corporations and other industries? A. Yes; where the government have fed the railways, and the time comes when they have a surplus over and above a reasonable dividend upon the capital invested, I think part of it should come back to the country. But where a railroad has not received any financial aid from the government, and when they come to make some money the government says "We want some of it," I do not think that is right. The same with the nickel industry.

Q. That would apply to the pulp business? A. Yes, practically.

Q. Where people spend a lot of money to create the pulp industry on a sound foundation, would they come in line with your remark? A. Yes, any business proposition. Even electric power, for that matter.

EVIDENCE AT COBALT, 28TH SEPTEMBER, 1916.

Mr. Arthur A. Cole, Mining Engineer, Temiskaming and Northern Ontario Railway, and President Canadian Mining Institute

MR. YOUNG: Mr. Cole, have you given any thought to the matter of taxation? A. My personal opinion is that there are a number of methods of taxation, and probably the one that would work out best for us here would be a combination of those different methods.

Q. When you say here, do you mean in Ontario? A. Yes, or in Canada generally. There is a general feeling, I think, among mining men that the proper method of acquiring mining lands from the government should be by lease instead of in fee simple; making the rights

of the holder practically the same as if he held in fee simple. If certain conditions, which might be made quite elastic, were not complied with, eventually the land would go back to the Crown, and there would not be the difficulty that we have in a good many parts of Ontario, where the title to lands is so tied up that capitalists will not touch them at all, because they cannot get a clear title. After a certain number of years, should the rental not be paid, the lands would revert to the Crown, and the next holder would be sure of a good title. A good many object to the word "lease," but such a tenure could be made just as secure as a grant outright. That would be a method of taxation, a small acreage taxation, for all mining lands that are acquired or secured from the Crown.

The Acreage Tax

MR. GIBSON: You are aware, of course, there is now an acreage tax? A. Yes.

Q. Would you suggest any change in that? A. I don't know just how much that tax is.

Q. There is a tax of two cents per acre upon mining lands in an unorganized district, but where a municipal organization has been set up, the tax ceases to be levied? A. Well, I think on unworked lands that might easily be increased with advantage. That would not apply to any working properties at all.

Q. Have you any figure in your mind? A. Well, I would rather not mention a figure, but I think two cents is too low.

Q. You said that in the event of a leasing system being adopted, if certain conditions were not complied with, the lands would revert to the Crown. You have mentioned one condition only, that is, if the annual rental failed to be paid. Had you any other condition in your mind? A. That was the only one. My idea was that it should be easy for this land to come back to the Crown on account of the non-payment of the annual dues over a certain period. I wanted to suggest that it be made in such a way that the lands would not be forfeited on account of any small technicality.

Q. For how many years' unpaid rental would you forfeit? A. Say five or ten years. There is much idle mining land in Ontario that would be working to-day if the titles which have been clouded perhaps for the last fifty or sixty years, could be cleared up.

Q. You are probably aware that the leasing system was in force for a long time in Ontario, beginning in 1891; that a large acreage of mining land was put under lease, and that a large proportion of these lands did revert to the Crown? A. Yes. The Canadian Mining Institute a number of years ago was asked to suggest certain basic principles on which a mining law could be drafted for the Dominion of Canada, and one of the principles they recommended was that lands should be leased.

Q. Have you observed any objection on the part of prospective investors to acquire lands under lease instead of in fee simple? A. Some of them do object; but it does not seem to work out adversely in Mexico, or other countries where they have the leasing system; and if it is made clear that the lease is of a permanent nature and can be held by a small payment, I think a title could be made just as secure as if acquired outright.

Q. In the United States and Great Britain, the countries whence most of the capital comes to Canada for mining purposes, are investors prepossessed in favour of the fee simple plan? A. I think they are, but that could be overcome. We have an illustration right here in the Province of Ontario. On one side of the Montreal river, if you get a prospect you can acquire a patent. On the other side of the river, in the Temagami Forest Reserve, you can get only a lease, but if your find is good you can get capital for it.

MR. YOUNG: How would that apply to taxation? A. In taxing the lands, I would divide them into three groups. The new and unworked lands, the lands that are being worked but not yet on a paying basis, and those that are on a paying basis; and this would apply to the first of those, the new and unworked lands.

Q. The acreage tax would be all that the State would get from them? A. Yes, that is all the suggestion contains.

A Small Tax on all Producing Mines

Q. And what would you suggest that they pay during the stages of working and not paying? A. I think that any mine actually producing ore should pay a small amount of taxation, and on that assumption I would suggest a very small tax levied on the gross output. For instance, on silver, a small tax per ounce produced, and gold the same way. That is, a small tax simply to help out the taxation of the Province, and at the same time not to constitute a hardship on the mining industry.

MR. GIBSON: That tax would accrue regardless of whether the mine were profitable or unprofitable? A. Yes.

Q. You would not suggest anything that would be detrimental to the investment of capital? A. Not at all, no.

Q. Out of what source could an unprofitable mine pay taxes, except capital? A. It would have to be considered simply as one of the working expenses; but the main tax must, I

[*A. A. Cole.*]

think, come from profits, very much as they are calculated now in the three per cent. Provincial tax.

MR. YOUNG: Then, do I understand you would have three systems working; first, a rental system applied to the first class of new and unworked mines; a gross output tax on the working mines that were not paying; then a net profit tax on the mines that were making a profit? A. No. The main taxation should be on the profits; it should be made to cut out the other taxes as the mines came into the profitable class.

Q. Why require a non-profitable mine to pay taxes on its output? Simply for revenue purposes? A. Simply for revenue purposes; it is looking forward to becoming a revenue producer and should be taxed, I think. Any mine that has ore would be in a better position to pay taxes than mining lands that are not being worked at all.

Q. There would seem to be this difficulty, that if a man didn't work his claim at all, he would pay only the acreage tax? A. Well, there is that objection.

Tax on Profits the Fairest

Q. If he could make profits there would at once be taxation on his output; and perhaps the mining profit tax on the whole is fairest? A. Undoubtedly. I think that is where the revenue should come from. It was not with the idea of placing any load on the working of the lands that I suggested an output tax. It was simply because any company that had ore it could ship, is likely to be in a better position to pay taxes than those who have lands lying idle.

Q. Have you given any consideration to the ad valorem system of taxation; that is, the system by which mines are actually valued and the mining company is assessed and taxed on that value? A. I have, but I don't think it is feasible at all.

Q. Speaking generally, or with reference to conditions in Ontario? A. Speaking generally.

Q. You know, of course, that in Michigan and Minnesota the iron mines are valued officially, and are assessed and taxed at the value placed upon them by the assessor? Do you regard that as a system which is applicable to Ontario? A. No, I do not. I think that in certain cases that could be applied to iron and nickel, but to the precious metals it is inapplicable entirely.

Q. Conceding that; would it apply to nickel or other deposits that have been proved to contain a very large tonnage of ore? Why isn't that just as easy to guage as iron? A. Well, I have not given that enough consideration to say.

Q. Do you think the present system of taxation on the net profits a just and equitable system? A. I think so. That is the best way of levying whatever taxes the mines have to pay. Then, no heavy burden is put on those that are in the non-productive stage.

Q. Are there any features in our present system that occur to you as requiring any change? A. I haven't come across any. It seems to be working satisfactorily. The T. & N. O. Railway Commission have lands leased to certain companies, and the basis on which we calculate our royalty is the same as that on which the Province collects the three per cent. mining tax.

MR. GIBSON: Is there anything else, Mr. Cole, that you would like to say? A. There is just this: I don't know what the other mining men will have to say, but I would just like to call your attention to the fact that if the present methods of taxation are all upset, it will materially hinder the bringing in of fresh capital from the outside to develop new prospects, and will discourage the mines that are already working. I am sure the members of the Nickel Commission will appreciate the importance of the mining industry to the Province as a whole. In collecting a few figures the other day, we were able to show that it cost annually to run the Cobalt camp about $7,000,000. This sum would not be expended in the Province if it were not for the silver mines, and the influence of that expenditure is bound to affect the material prosperity, not only of this district, but almost every other part of the Province in one way or another. In suggesting any changes or alterations in the method of taxation, I am sure the Nickel Commission will take all of that into consideration.

Lt.-Col. R. W. Leonard, President Coniagas Mines Limited, St. Catharines

MR. YOUNG: With regard to taxation, Colonel Leonard, what are your views as to the present system? Is it satisfactory to the mining community, or do they desire any change?

Unworked Lands Should be Taxed

A. I am strongly of opinion that unworked mining lands should be sufficiently taxed to prevent them being held indefinitely as undeveloped properties; I would favour an acreage tax as at present, but I do not see why organized territory should be exempted.

Q. The same rule could be applied to both organized and unorganized districts? A. That is my impression.

[*A. A. Cole; R. W. Leonard.*]

MR. GIBSON: What would you say as to the amount of the present tax? Do you think it is sufficient to effect that purpose? A. It is only two cents an acre. It seems to me very small. I think it could be increased without hardship to people who really intended to develop, and perhaps to the betterment of the whole industry.

MR. YOUNG: Would a tax of five cents an acre have the effect you suggest? A. I would not like to speak too definitely on it, as my knowledge is not great; but it would not seem to me that five cents is excessive.

MR. GIBSON: Would you favour exempting from that acreage tax such lands as are worked, or it is worth while to do so? A. If lands are actually and continually worked they bring indirectly into the Province business and returns which might be considered of more value to the Province than the tax, so that possibly it might be as well in such cases to remit the tax. It might be a slight incentive toward working.

MR. YOUNG: I am wondering if the difference between two cents and five cents would have the wholesome effect you suggest? A. I doubt if it would, and therefore I say five cents in my opinion is a very small tax.

Q. If the object is to stimulate the working of a claim, the difference between two and five cents is not very much on a forty-acre claim? A. If paying such a tax on a forty-acre claim isn't worth while, it couldn't be of much value to the owner.

Q. You think a substantial increase in the tax on unworked lands would not be at all unreasonable? A. I think so.

MR. GIBSON: Then your suggestion of a substantial acreage tax would have a two-fold object: first, to stimulate the working of the land; secondly, to cause it to revert to the Crown and so clear the title if the owner failed to pay? A. Quite so.

Q. Both of these objects would be advantageous? A. Yes.

No Fault to Find with Profit Tax

MR. YOUNG: What are your views as to the best taxation on a profitable mine? A. Well, I don't think that mine owners have any desire to escape a just share of the taxation necessary for the government of the Province or of the Dominion. We have become accustomed to the 3 per cent. tax as exacted by the Province, and speaking for our own property, we have no reason to find fault with it. We consider it as good a method of obtaining a revenue as any we can think of.

Q. Do you thing it is fairer to the mining community generally than the output tax would be? A. Yes. It would be difficult to value the properties for taxation purposes, especially properties producing complex minerals, such, for instance, as these at Cobalt. There would be the question as to the valuation of the nickel and arsenic and silver in these, and how much profit, if any, there is in producing these things. We have other complex minerals in the Province, so that I think there would be great difficulty in the administration of such a law.

MR. GIBSON: One desirable quality in any method of taxation is certainty; it should be easily understood? A. Yes.

Q. You think that quality is possessed by the present system? A. I think it is.

Q. How would you regard the system such as obtains in other parts of the world, for instance the United States, based on the value of the mine? A. I think it would be very difficult to establish the value of the mine. It might be a very good thing for mining engineers employed to value the mines from time to time. I think it would be principally beneficial to them.

Q. Do you regard it as suitable to our conditions in Ontario? A. No.

MR. YOUNG: Have you any suggestion with regard to the portion of the tax that the municipality should get? The arbitrary figure is one-third, with the exception of Cobalt, which gets one-half? A I don't know that I am competent to express an opinion on that. I have not gone into it at all.

MR. GIBSON: It doesn't matter to the mine owner? A. It doesn't matter to the mine owner, no.

MR. YOUNG: Well, in some cases it might matter to the mine owner. If the taxes he paid were spent on local improvements, roads and the like, it would be useful to him in the operation of his industry? A. Well, giving my impression only, I think that the mine owners in Cobalt have had the view that the municipality has had a good fair share of the taxation for its local expenditures.

[R. W. Leonard.]

Mr. R. B. Watson, General Manager Nipissing Mining Company, Limited, Cobalt

MR. YOUNG: Mr. Watson, we should like to hear your views on any of the subjects that are up for discussion, especially with regard to taxation?

Present System Satisfactory

A. I think, as far as most of the mines in Cobalt are concerned, the present system is working very satisfactorily. We are used to it now, and the tax is collected very easily, largely due to the collector, Mr. Mickle. I do not see how you could improve it. I would not think it advisable to adopt any other system, or have half a dozen systems working at the same time. This is a very simple method, and it places the tax on those who can best afford it. I think that a tax on the output of the mines, or on the tonnage of ore, is inadvisable. As to increasing the tax on mines: well, everybody is glad to contribute his proportion during the war. The Dominion war tax is looked on as only a war measure, and it would certainly discourage investing in Canada or Ontario if the government put on a permanent tax in excess of the present one. I think there is some feeling in the States that it is unsafe to make investments up here, on account of the uncertainty as to what the government is going to do in the way of taxes. You noticed all the stocks a little while ago went down, and a great deal of explaining is still necessary to some of the men down there that this isn't going to be a permanent thing.

Q. Do you think the owner of valuable mining property that is not worked might be left alone until such time as it is working at a profit? Take the case of an unworked property on which there are all reasonable indications of value: under our present system that man escapes taxation except a nominal acreage tax. Some hold that class of property should be taxed? A. I think if a man has a good mine the first thing he wants to do is get his money out of it. There are very few valuable mines in Ontario that are not being worked.

Q. That is, you think the owner's self-interest would take care of that case? A. Yes.

Q. Cases of the kind have been brought to our attention in the United States? A. Occasionally, a man cannot work his property; cannot get together interests that won't agree; but I think such cases would be a very small proportion of the whole.

Q. You think a proper system of taxation would disregard that exception? A. Yes. As far as the prospector goes, it is difficult to devise a system which gives the prospector a sufficient incentive to find a mine, and at the same time will avoid tying up too much prospective mineral ground.

Mexican Law a Good One

There are good points about the Mexican system. There, no assessment work is required on the property, simply an annual tax. It used to be \$3.00 for about 2 acres. On a 40-acre claim here that would be about \$60.00 a year. The trouble with this system is that with an unstable government it is open to abuse. Since the war started in Mexico, two or three different factions have tried to collect a tax for the same year, and the mining companies had to pay a tax several times in order to avoid losing control of their property. The government has now largely increased this tax until it almost amounts to confiscation. The tax per acre increases with the number of acres held by the same company, so that a company with a large acreage is paying several times as much per acre as the man with a small acreage. Investors are very shy about going into a country where they cannot get the land in fee simple. There is no doubt in my mind that the principle of doing so much work a year on an unpatented mining claim is bad; probably half or three-quarters of the so-called assessment work is useless work, or is not done at all. If a man were required to pay into the government half as much in money as he is supposed to do in work, it would enable the government to spend that money on the mining lands in some useful way, whereas now, it is largely wasted.

Q. Would you ear-mark that money for development work? Would you stipulate that the State should use the money for development work, or as general funds? A. General funds for the use of the mining industry; that is, to develop the mining country, build roads or something of that kind. In this country any man can get a job that wants to, so that he cannot have any valid objection to paying the money rather than doing the work.

MR. GIBSON: Isn't there something in the idea of obliging a man to work his claim in order to discover if there is any deposit? A. Yes, that is the assumption, but he isn't going to keep on paying the taxes year after year without trying to work it himself, or get somebody else to work it. In the present way he is enabled to hold a whole lot of ground by doing very little work.

Q. You are referring, of course, to unpatented claims, because after patent is issued no further work is required by law? A. Yes.

MR. YOUNG: How would you deal with patented land? Would you put on a more substantial acreage tax? A. You mean patented ground that is not being worked?

Q. Yes. A. Well, if the two could be worked simultaneously, it might be a good idea to collect the tax unless the land is worked.

[*R. B. Watson.*]

Two-Cent per Acre Tax a Joke

MR. GIBSON: There is at present a Crown tax of two cents an acre. Do you think that sufficient? A. No, I think it is a joke.

Q. Do you think an increase in that tax would have a deterrent effect, or work any hardship, on the prospector? A. It all depends how high it would be.

Q. I suppose the amount of the tax is a matter of opinion. A. I think it would be a good idea for the Province to take out of the hands of the township the right to assess mining lands, because the thing is so mixed up now that one township will assess a mining claim that isn't being worked at a small sum, and the next one will assess a similar claim for a thousand dollars.

Q. There is a provision in the law with reference to that: mining lands are assessable at not less than agricultural lands in the same district; minerals in the ground are not taxed, nor are the buildings of a mine? A. Take the case of Porcupine; there are many claims up there not being worked, and they are not taxed as agricultural land. There are many claims in the woods, not worth anything apparently, assessed at $800 a claim.

Q. The law provides a remedy for any person who deems himself over assessed; he has the right to appeal? A. I think the right of the township to assess at all should be limited.

MR. YOUNG: The danger is, you might drift into the valuation of mines, for which the rural assessor is wholly incompetent; everybody concedes that? A. Yes.

Q. I think we have your point, that there is a hardship and an inconsistency; in some cases there is very low valuation, and in other cases a very high valuation without what, in your opinion, is sufficient justification? A. If you are going to put a considerable acreage tax on patented mining claims that are not being worked, then the township ought to take the same valuation that you put on, or else get part of the taxes that the Province would collect from that source.

MR. GIBSON: If the theory is sound that pressure should be brought to bear upon the owner of undeveloped mining lands to work them, wouldn't the pressure of heavy taxation on such lands in organized townships have the desired effect? A. Yes, it certainly would.

Progressive Tax Rate Objectionable

MR. YOUNG: Have you ever considered a progressive tax? Should a mine making a profit of twenty thousand dollars a year pay a lower rate than one making a million dollars a year? A. The idea is popular with those who have nothing to tax.

Q. It is a principle that is pretty generally adopted now in other assessments, such as our Succession Duties Act, and, in fact all the world over, whether it is right or wrong? A. Personally I think it is wrong; but all that kind of legislation is mixed up with politics now to make the rich man pay more for each dollar of his income than the poor man does. That is the reason for it, whether it is just or not. It comes back finally to this: if we pay excessive taxes in the mining industry, it will discourage other investors from coming in here, and will hold back the development of the country.

Q. Do you regard the present system at all as having reached that point you speak of? A. No, I don't think so, to people who understand thoroughly the conditions; but as I have said before, in the States they are wondering how far the government will go in taxing the mining industry here, and that has had some effect in considering new properties in Ontario at this time.

Q. I might point out to you, though you may be already aware of the fact, that in the State of Michigan the taxation of mines has risen to 15 per cent. on the gross profits; far beyond anything that has ever been suggested here, and that in one year the profits on iron ore to the mine owners in Michigan was 25 cents a ton, out of which they paid 14 cents in taxation; yet the iron mining industry of Michigan is going ahead. I don't mean that that is an ideal condition; but I am just pointing to it in connection with your remark in regard to Ontario. But, generally speaking, is it your opinion that the present system in vogue in Ontario is a just and equitable system? A. Yes, it is.

Q. And you don't suggest any change? A. No, I think we are all right as we are.

Mr. Tom R. Jones, General Manager, Buffalo Mines, Limited, Cobalt

MR. YOUNG: Well, Mr. Jones, we shall be very glad to have your views on the question of taxation. You have heard Mr. Watson's statement; do you agree with him in the main? A. I think a general scheme should be worked out in connection with the taxation on mines in townships which are open for settlement or prospecting; but a just tax should be levied by the Province to provide for the construction of roads and highways and schools.

Q. On all lands, whether mining or agricultural? A. Yes, as soon as the land is applied for under a prospector's license it ought to be subject to taxation, and when there is a demand for roads and highways the Province should take immediate steps to construct

them on a fixed policy, for which there would be set aside a certain sum, and this would regulate the taxes in that case. I don't think you can make a fixed rate except for a particular township.

Q. I don't understand how you propose the money should be raised? A. The Province should issue debentures, which it could redeem by the charges levied against the land.

Q. That would have to be quite a substantial tax? A. Well, people are willing to pay it. If roads go through they benefit all and relieve distress and hardship.

Q. You would retain that fund for a certain time? A. Yes.

Q. And build your roads with it? A. A nominal sum could be fixed against townships where there was no expenditure.

Q. And you would collect the moneys expended in that township from the lands in it? A. Yes.

Q. As they were taken up? A. As they were taken up.

Q. And if the taxes were not paid the land would revert to the Crown? A. It would be government property.

MR. GIBSON: These settlers would mostly be poor men; would they be able to pay much of a tax? A. Well, reduce your rate of interest, or extend it over a longer period, say 100 years. If you don't do that, you spend the money all in one lump, or it all comes out of the general funds of the Province. It would be the same thing, only a different means of distributing it. In the townships of Teck and Lebel, they are figuring on organizing a municipality, and wish to take up the question of roads, highways and schools immediately; something of that kind will have to be done.

Q. That, of course, is not specially mining taxation; it would apply to all lands? A. Yes, and there is no reason why some such scheme could not be carried out.

Q. There would be no distinction between a mining claim and agricultural lands? A. No, it would be all on the same basis. It would extend over a long period of years, making the rate of interest comparatively small.

Q. Speaking now with regard to the present system of taxation of mines in Ontario? A. I prefer the present system of taxation on the net profits.

Q. You think it is a just and equitable system? A. I think it is a most satisfactory system. It is something definite and well understood, and it is one that we can fix our books up each quarter to comply with.

Q. Have you any suggestion about amending the Act in any way, or do you think it works fairly well as it is? A. I would heartily disagree with any attempt to adopt the Minnesota and Michigan plan, which we hear so much about. I was in Minnesota when the agitation was on, and it was a straight political move, because the mines had no representative in the Legislature, and we simply got the worst of it. It caused a big fight in Lake county. The agitation was supported from Duluth, where they kept all the revenue and spent it. We never got a nickel of it for highways or anything else. The miners finally got a representative in the Legislature, and in the end managed to have a good deal of revenue raised by the tax expended in the locality. They have now in Lake county a very good school system contributed to solely by the miners. The ad valorem plan has worked out most detrimentally in Minnesota. The minute a man starts exploration he is assessed; there is no time to develop a proven ore body by diamond drill work or otherwise, and had this system been adopted twenty years ago the known iron ore reserves of the United States would have been a small item compared with to-day. To my idea it is essential for the Province or the government in the matter of ore reserves to know what you have got. That is information only: it is not actual value. The last iron ore the Steel Corporation take out will cost them about $18 a ton.

Q. I need not ask for your opinion of that system in Ontario? A. I think the Province and the government should know what the ore reserves are as they are determined, in order to form a correct appreciation of the possibilities of the mining industry.

MR. YOUNG: We appreciate the difficulties, but there is a difference between valuing iron ore and valuing the precious metals, gold and silver? A. I don't think it is a good proposition. You might develop by diamond drill a large percentage of low grade ore which is not of commercial value. It would be taxable in Minnesota, and it is no asset. On the other hand, you may have commercial ore in unproven ground, but the ad valorem system discourages exploration, and it remains unlocated.

Mr. Samuel W. Cohen, General Manager, Crown Reserve Mining Company, Limited, Cobalt

MR. YOUNG: Well, Mr. Cohen, what are your views on our present system of taxation? A. I think the system is pretty good as it applies to Cobalt and the precious metal mines especially, but I think one of the reasons it works out so satisfactorily is because of the individual merit of the assessor, Mr. Mickle.

[T. R. Jones; S. W. Cohen.]

Case of the Nickel Companies

Q. The tax collector isn't generally a very popular man? A. The only point that seems to be not clear in the matter is apart from these mines here. It is very easy to tax the net profit in Cobalt or Porcupine, but we are not sure whether we are getting a perfectly square deal as things work out, as far as the nickel mines in Sudbury are concerned. If we owned our own smelters, for instance, and ran them as an independent company, we could reduce our profits at the mine and would not have to pay as much taxes, yet at the same time we would be earning as much money. That is an indefinite point, which should in some way be cleared up.

Q. That is the troublesome question of the value of the ore at the pit's mouth when there is no market for it? A. Exactly.

Q. Now, what are your own views as to that; how would you deal with that situation? A. Well, I would simply take the value of the refined product and figure out what it cost to refine it, and allow a fair profit on it; after all, the refining is a commercial operation; the process is no secret, and is not covered by special patent any longer, therefore it isn't entitled to any more than a fair profit.

MR. GIBSON: What about the smelting stage; wouldn't you allow some profit for that? A. Oh, yes. I mean, the matte goes to New Jersey, and they claim that the only reason it has a value is because they know how to refine it.

Q. Supposing you were to apportion the profit over the three stages, mining, smelting and refining, in terms of percentage. What, in your opinion, would be a fair proportion to allow for the several stages? A. I don't know about a particular case, because I have not gone into details, but everybody knows what it costs to smelt. Take the cost of the coal, and the freight rates and so on. It is not a matter of chance or uncertainty or probability; it is a straight question of business. The same is true of refining. Mining is the indefinite end of it. Now, we have to pay taxes here on the profits that we make in the individual mine without any consideration of the chances we take in the refining of that metal. That is, for instance, the Crown Reserve mine pays a tax on the net profit of the Crown Reserve. It takes no cognizance of any money the Crown Reserve has to spend.

Q. Is that view correct? There is an allowance for depreciation, and isn't the cost of new work on this mine or on other mines of the same company deducted from the profits? A. I don't think it was ever deducted from us.

Q. Well, has the Crown Reserve Company ever spent any money in this way? A. Yes, it developed the Porcupine Crown gold mine.

Q. Isn't that a separate company? A. Yes, it became a separate company to operate that mine. Mining must be considered as a special business, more subject to chances and risks than the subsequent operations of smelting and refining. Therefore if we here go ahead without trying to make any arrangements for separate companies to save certain moneys and should pay what seems to be a legitimate tax, everybody else should do the same. That is, there should be no loophole for them to get away.

MR. YOUNG: There is this difficulty in this case, your product of silver has an easily ascertainable value? A. So has nickel.

Q. Is your idea to take the market value of nickel and then deduct the cost of smelting and refining? A. You could carry that through to its logical conclusion, and find out what they actually get for the nickel.

Q. I would just like you to put yourself in the position of the Mine Assessor; how would you work out the nickel situation in the case of the International Nickel Company? A. Well, if the nickel refining was done by one company, and the smelting by another, there would be no trouble whatever about it, would there?

Q. No, because there would be a contract fixing the selling price? A. Now, then, put the case under present conditions. It doesn't make any difference whether I sell ore to myself or anybody else; the smelter makes a certain profit, and the refinery makes a certain profit. The refineries and smelters don't take any chances, where the mining company does. They locate at a given point, and they know that there are certain ores they can draw on, and they are entitled to a certain profit. In the case of companies trying to use foreign organization to get away from the tax, the only way is to tax the profit on this industry which takes no chances.

Q. Aren't you there in this difficulty, that the Province cannot tax works outside the Province under the B. N. A. Act, which gives the Province all the powers of taxation it possesses? It is said to the Mine Assessor: "The nickel in the matte is worth so much; what gives it the remaining value is our refining process, which is carried on outside of your jurisdiction altogether." Now, how would you proceed to ascertain the fair value of the nickel and copper in that matte? A. The only answer I can give to that is to ask another question. Suppose we did that with silver ores?

Q. Well, you have got a selling value there? A. So have they got a selling value. They know what the product will bring.

Q. We don't know that? A. They know. There is no reason why they shouldn't. Under the terms of the Crown Reserve purchase from the government we pay a 10 per cent. royalty which includes the 3 per cent. tax; and if we wanted to get around that, what is the matter with our buying a little refinery right over the line, and selling that ore to ourselves for nothing, or a small amount per ton? I am sure the government would not have stood for it, because it would be a special case which they could take up, and I think something should be done with the other people. They are a big company, earning tremendous profits, and they ought to pay their proportion of the taxes. We have no kick coming, but we don't want to see anybody else getting away with something that we cannot get ourselves.

Would Tax Undeveloped Lands

The only other point; patented lands should be taxed to cause them to be worked.

Q. What would you tax them? A. I would tax them enough to make it worth while; something substantial.

Q. Twenty-five cents an acre? A. At least that.

Q. What do you think of Mr. Jones' suggestion? A. I didn't catch all he said, but I know about Minnesota, as I came from there. The conditions are very different. An iron mine has a certain amount of ore; you can see and measure how much there is; and it has a market which does not vary much; therefore you know just about what the mine is going to produce, and can put a tax on it. And by the way, a great part of that tax goes to the University of Minnesota, to which I went, and which is probably the best institute in the world as a result of the revenue thus obtained. But that is a special method which might apply to coal and iron. You could not very well apply it to other mines. There will always be trouble and disputes.

Present Tax Law All Right

This present arrangement is a good arrangement.

Q. Both in theory and practice? A. Yes. The man that makes the money should pay the tax. Everybody that is making money out of mines should share it. It should not be possible for any company or any organization to get away.

MR. GIBSON: I don't know, Mr. Cohen, whether you got the import of my question with regard to the nickel situation. You say you would work back from the price received for the nickel? A. If you could find out that price.

Q. Well, assuming we know what they sell it for, you would deduct so much for refining, and so much for smelting, and the balance would be the value of the ore? A. Yes.

Q. Could you put the share of the total profit that you would allot to each of these respective stages in the form of a percentage? Take 100 as the whole. How much would you allot for profit on the refining, the smelting and the mining? A. I wouldn't put it that way. I would give the refining a definite profit on its operations.

Q. I am asking what percentages? A. That would all depend on how much their costs are and their profits, but I mean those costs should be fixed. Suppose you sell ore to Colonel Leonard, who is in the Province, and he makes a hundred thousand a year on his refinery, representing, say, only five or ten per cent. on his investment, you wouldn't think that that was anything but a fair profit; they should have a fair return on the treatment of the ore, but I don't know how the profit is to be proportioned.

Q. Would you take into account the capital employed, the amount of labour and so on in each stage? A. I figure that the smelting and refining is an industry that is entitled only to the proportion of profit that similar industries make. It takes no chances, because it has a definite supply. It is true, it is incidental to the business, but it is no more incidental than anything else, and the very fact that the International Nickel Company controls practically all the nickel mines in Canada and therefore can have its own refinery, puts it in a different position than if other nickel miners in Canada should pay some refinery here to refine their ore.

Q. Possession of the ore is the real basis for any mining company? A. Of course.

Q. That goes without saying; but because of that, should a larger share of the profit be allotted to the mining than to subsequent operations? A. In certain cases. There are other ways of refining nickel than the International Company's process, but all the refineries in the world couldn't pay unless they had the ore.

Q. You would, then, take the value of the refined nickel, and deduct from the cost of refining a reasonable amount for profit, and you would tax the balance, less the cost of smelting? A. On the mine, yes.

Q. Suppose you could not ascertain that cost, you would do the best you could? A. Yes, you would have to do the best you could.

Q. Col. Leonard's books would be available to a Mine Assessor; the books of an outside company would not? A. You can find out; there is no trick in it.

[*S. W. Cohen.*]

Mr. B. Neilly, Manager, Penn-Canadian Mines, Limited, Cobalt

MR. YOUNG: Well, Mr. Neilly, you have heard these gentlemen. Have you anything to add to what they have said? A. I simply affirm again that unless very radical changes are to be made in the system of taxation, the present one is quite satisfactory, now that we are used to it, and capital appreciates just what it means. I would combat the suggestion of a tax on the gross output by merely referring to the fact that on certain commodities the government pay a bounty on the gross output.

Capital Should be Returned Before Profits Taxed

None of us know very much, I suppose, about the proper method of applying taxation, but in a mining concern it must always be kept in mind that you must get the amount of the investment out before you make any profit; and that until the company has produced enough profits to return the capital invested, the present tax even is a penalty on the best mining proposition. It cannot be adjudged otherwise. In the United States I understand that the usual depreciation allowed has been five per cent., and that has just been changed, and I am informed that there will be no profit tax until the value of the property at the time this law comes into effect has been returned to the shareholders.

MR. GIBSON: In what State is that law? A. I got that information from Mr. Watson just now, and I suppose it would be in New Jersey. I think that is where the holding company of the Nipissing is chartered. He told me that it applied to them, so that must be where the change is made, and there will be no profit tax until the gross value of ore reserves as reported at the time the mining law was brought into force has been repaid to the shareholders. That, I think, is a very fair position.

Q. You think that a fair allowance should be made for the capital invested in a mine, in the way you speak of? A. Yes.

Q. Without any relation whatever to the amount of the capital stock of the company? A. Oh, absolutely no relation.

Q. So that if a company developed the mine at a cost of $100,000 you think they should be allowed to retain their profits up to the amount of one hundred thousand dollars before they begin to pay any taxes? A. Yes. Otherwise you are penalizing them for putting their investment in that particular channel.

Q. Would there be any difficulty in ascertaining the amount of capital invested in any particular mine? A. Yes. That is the whole difficulty.

Q. Well, isn't it a serious difficulty? A. That is a serious difficulty, yes.

Q. Isn't one of the chief advantages of any tax its definiteness and certainty? A. That is one of the reasons, as I say, that the present form of taxation is as good as anything I can suggest, or have heard suggested, unless you go to the extreme and make an allowance for capital invested from the time of the profit tax being imposed. I point that out merely as a weakness in the present method.

Q. But you may find it not easy to suggest a remedy? A. Not easy, no, although at the present time we are paying a three per cent. tax on profits, whereas we have not yet paid a dividend.

Q. Would you regard a sum that a company might pay for a claim as a sum that should be deducted from the profits before taxation accrued? A. I don't think there could be any simpler matter.

Q. If a man paid $2.50 an acre to the government for a forty-acre claim, that would be $100, and if he developed a profitable mine, would that be the amount he would be entitled to deduct? A. On the other hand, another man might buy a similar mine from a prospector and pay a hundred thousand dollars for it, and he would have the right to deduct that hundred thousand before paying a tax.

Q. Is it a difficult matter to calculate your reserves in the silver mines at Cobalt? A. It is almost impossible. You can make an approximation in some cases.

Q. But it is largely conjectural? A. Yes, and if you go to buy a property you have got to pay for far more than the actual ore reserves. In the case of the mine I am manager of, there was nothing in sight when we bought, and we paid a hundred thousand dollars for it.

Q. You took a chance? A. We took a chance, and paid a hundred thousand dollars for the chance. I think in the abstract a man has a right to have his capital returned before you tax him on the profits, if there is any possible way to get at it, but I don't think there is.

Increase the Acreage Tax

MR. YOUNG: But with that suggestion you approve of the present system? A. Yes, absolutely. I think I would be in favour of increasing the acreage tax, although as I understand, it doesn't really represent a tax. It is merely a means of getting title to the property; it is not really intended as a tax.

[*B. Neilly.*]

MR. GIBSON: It produces some revenue? A. Yes, but still it doesn't amount to very much. I think everything should be done to encourage the prospector up to the time at least that the patent issues. There should be no heavy tax on him. I would suggest to exempt the prospector from the tax for a period of a year or so after the patent issues, and then make it fairly heavy so that the claim will either be developed or turned back to the Crown, and give somebody else a chance.

MR. YOUNG: Make the acreage tax fairly heavy after a reasonable period to oblige the owner to do something, or dispose of it? A. If a man hasn't produced anything of value in three to five years, the chances are he is not going to.

Q. And you would make that a substantial tax? A. Yes.

Q. Twenty-five cents an acre would be little enough? A. Why, I would be inclined to favour something over that.

Q. You think that would be wholesome on the mining industry? A. I do, yes. We have enormous acreages tied up under patent that nobody has a right to go on and prospect, and the owners make no move to develop their property. The parties that own the lands may be quite certain they are no good, but are holding them on the off chance.

Q. Would you make that in addition to the tax the assessor puts on? A. You mean in organized territory?

Q. Yes. A. I don't feel competent to express an opinion on that. I would not care to say, because the townships vary considerably both as to assessed value and the tax rate.

MR. GIBSON: There is pressure now at that point on the owners of undeveloped land, which should tend to induce them to develop it? A. Not very much. I think it is ten dollars an acre; a forty-acre claim would be $400 and the rate is ten mills. Four times that is not enough.

Q. Ten mills is the average rate? A. Yes, I think that is the rate in the township of Coleman this year, and the taxes derived from this assessed value amount to something like $9,000.

Q. There is no assessment on the mines? A. No, their other income from profit taxes amounts to, I think, about $21,000.

Q. Are you able to express any opinion as to the distribution under the present Act between the government and the municipality? A. There was one thing which struck me in looking into that, and that was the township's proportion of the profit tax, a little more than took care of education in the district; I think that is a nice point.

Q. The cost of the schools? A. The cost of the schools in the township was $17,000, and their income from that profit tax was $21,000. It assured education to all children in the township, and made it easy for the township to supply first class schools and first class teachers.

Q. And good roads as well? A. And good roads as well.

Mr. H. A. Kee, Manager, Kerr Lake Mining Company, Limited, Cobalt

MR. YOUNG: What can you tell us, Mr. Kee? A. I do not feel that I could add anything that would be of benefit, as everything has been pretty well covered.

Q. Do you agree or disagree? A. I feel that the taxes called for under present conditions are quite reasonable.

Q. You approve of the present system, in short? A. Yes, I do.

Q. And have nothing to suggest in the way of amendments? A. I have nothing to suggest. We are all pleased to pay excess taxes due to existing war conditions, but once any change is made, it is likely to be a radical change and may be injurious.

Q. You agree with the suggestion that patented lands which are not developed might stand a substantial acreage tax? A. Yes.

Q. You would not express an opinion as to an increase in the profit tax? A. No.

Q. The amount of that tax should be left to the authorities? A. Yes, after your investigation is concluded.

Q. And I assume you would like it to be as low as possible? A. Yes, we feel we are paying a fairly good proportion under the present conditions.

Q. I don't suppose you have looked into the percentage that is paid on the American side? A. No, I have not.

Q. Taxes there are heavy as compared with ours? A. Yes; they have been increased considerably in the last few years.

EVIDENCE AT TIMMINS, 2ND OCTOBER, 1916

Mr. H. E. Montgomery, Town Clerk, and Mr. E. H. Hill, Assessor and Fire Chief, Timmins

MR. YOUNG: Well, Mr. Montgomery, you have been good enough to give us a statement here showing assessment, taxation, etc., in Timmins, and we are obliged to you for the time and trouble you have given to it. I don't know that it calls for much, if any, explanation, but it is a fact that there are no arrears of indebtedness on any of the debentures that are mentioned in the statement? A. Yes.

Problems of Municipal Finance

Q. Are you contemplating a further issue of debentures? A. Yes.

Q. How much would that be? A. The public school would call for about $35,000.

Q. Will that be a ten-year issue? A. Well, it all depends on how we can sell them. If we cannot sell them to an outsider, the Hollinger Company will take them, and will want them to suit themselves; so we don't know yet whether they will be ten or fifteen years.

Q. And are there any others? A. Yes, some local improvements and sidewalks, but we don't know how much we need. We will pass a by-law authorizing us to borrow the money from the bank, and when we know what it is we will issue a debenture for that.

Q. That will not exceed five thousand, will it? A. I don't think so.

Q. Then, there is no pressing requirement for any further expensive improvement, is there? A. There is another issue of debentures authorized for $1,800 for patriotic purposes and things like that. We have paid the amount out of the general fund, and will have to reimburse it.

Q. You are going to recoup it by a debenture issue? A. Yes.

Q. You have given us here a list of the total taxes, 1912, 1913, 1914, 1915 and 1916, inclusive; that does not include what you call the royalty? A. No.

Q. Now, the column here headed "Income," that shows the ordinary receipts from income tax proper? A. Yes.

Q. Without regard to anything derived from the mines? A. Except from the employees.

Q. But not from the mining company? A. No.

Q. That is rather large assessment this year, isn't it—$381,056? A. Yes; that is what it is.

Q. So that you must give pretty strict attention to the income end of your taxation here? A. Yes, Mr. Hill looks after that.

Q. Mr. Hill is also the collector here, I understand. A. Yes.

Q. About what percentage do you lose in taxes?

MR. HILL: On income tax the loss is high, say thirty-three and one-third per cent

Q. What is that due to largely—people leaving? A. Yes. I get my return say in March of this year; well, ninety per cent. of those are men that come and go. Out of this 90 per cent., say 40 per cent. stay about three or four months at the mine. The result is by the time the tax bills aré out they are away, and we lose track of them.

Q. Unless they have something to tie them here in the way of property? A. If they have property I always get them. They sometimes come back.

Q. Would it help you to have periodical payments of taxes? A. Well, between the time you assess and the time you get your first payment there would generally be three months' interval. Then, you would lose a lot of them after that.

Q. Outside of the income tax, are the rest of your taxes pretty well collectable? A. Oh, yes. The business tax is all collectable.

Q. Just the same as in any other community? A. Yes; we have no property tax arrears.

Q. Is the bulk of the income tax proper from mine employees? A. Yes.

Q. But there are professional men and other people who are liable? A. Ninety per cent. are mine employees.

Q. And the other ten per cent. would be store clerks and professional men? A. Yes.

Q. How do you assess the mineral claims in your municipality that are not being worked or are not productive? A. We don't happen to have any. We have just got the Hollinger Consolidated property in the municipality.

Q. There are no mining claims just staked out and left in your town at all? A. No, we haven't got a piece of any kind.

Q. Do you know as a matter of fact, how they do in Tisdale? A. Yes.

Q. How are they assessed there? A. I understand that this year the assessor has run them as high as $35 and $40 an acre. I took it here at $10 an acre.

Q. I understood you didn't have any? A. The only mining property we have in town, is the Hollinger gold mine. Well, that land is assessed at $10 an acre.

MR. GIBSON: Practically all the buildings connected with the mine are non-assessable? A. Yes, the buildings used for mining and milling purposes and sorting of the ore, and

the office. The office is an expensive building: it cost upwards of $40,000. It is necessary to the working of the mine, not the whole building, but 75 per cent. of it. Of course, there is some elaborate accommodation there, such as that for the directors.

Q. And how do you do in that connection? A. Well, roughly, one flat that was used as recreation rooms, dormitories, etc., was all I assessed.

Q. That would be an assessment of about fifteen or twenty per cent. on the whole value? A. Yes, somewhere around there.

Taxes on Land

Q And in assessing the other real estate in the town, about what proportion of the cash value do you aim at? A. Well, this year, as near as I can give it, about 75 per cent. of its real value; I try to hold that up right through.

Q. There are sales from time to time that enable you to judge fairly well of the value? A. Yes.

MR. YOUNG: Have you had a real estate boom here? A. No, not since 1912.

Q. So that you are able to get a pretty fair idea of the true actual value? A. Yes.

MR. GIBSON: Is property in fair demand? A. Yes, there are very few vacant lots. In the business section there is not a vacant foot, and in the residential section I doubt if there are more than fifty or sixty lots for sale, and they cannot be built on because they are not suitable land. There are no vacant houses in town. There hasn't been a vacant house here to my knowledge for the last two years.

Q. The population is increasing? A. Oh, yes.

Q. Notwithstanding the recruiting and so on, you estimate that your population is growing? A. Oh, yes.

Q. Necessarily so, when the mines are expanding? A. The town has had a rapid growth ever since I have been here. It is wonderful.

MR. YOUNG: You treat your office buildings under sub-sec. 4 of the Assessment Act "Buildings, plant or machinery on or under mineral lands and used mainly for obtaining minerals from the ground, etc." A. Yes.

Q. So that the office buildings in this case are exempt, under that provision? A. Yes, that portion of the building used for office purposes.

Q. And then the boarding house, club houses and buildings of that sort? A. They are all taxed. I assess them at full value in comparison with the other property that is assessed.

Q. Is there anything that you would like to suggest to this Commission in regard to the taxation of mines, from your point of view as an assessor? A. Not in connection with the mining itself. I may say that we all like the mines to deal with. Never have any trouble with them; never even had an argument.

MR. GIBSON: There isn't much room for argument. They know the tax you are to get, and they are good business men? A. There is no chance. I don't agree over much with that income tax on the mine employees. As far as the mine itself is concerned, it is all right.

Q. What would you suggest as to that? A. I have heard there was a clause in a portion of the Act, I think I have seen it, where you can put this income tax on the staff, and apply a straight poll tax to the rank and file. I think if you could work anything like that, it would be more satisfactory.

Small Income Taxes Hard to Collect

Q. Well, $5.00 poll tax wouldn't give you as much as you are getting now on your income tax? A. I think it would, because you could impose that poll tax all year. The point is, the average list of mine employees numbers 1,000, and that 1,000 turns into pretty nearly 2,000 by the end of the year with the men coming and going and changing every quarter. There is approximately $10,000. If a man works only a week we would go after him for his poll tax; but I can see a difficulty in having both the poll tax and income tax, because at the mine when they are making the returns of 700 or 800 men, they don't know whether these men are residents or householders.

Q. And you have difficulty with the names of these foreigners? A. I don't mind the name so much.

Q Don't they change their name sometimes, and confuse you that way? A. Yes, they may change it three or four times, and there is no doubt about all these foreigners getting away to avoid paying their taxes. But the steady men at the mine pay year in and year out.

MR. MONTGOMERY: There is one thing which came into my mind. If we have the poll tax, and ask the mine office to prepare a list, we have got to be at the mercy of some clerk up there by agreeing to pay him a percentage, and then he may be too busy and can't attend to it as he should. If it was the law that employers should collect the tax from the men on the pay-roll it would make it easier.

MR. HILL: That is the only solution; and that would particularly apply to the foreigners. It would catch them.

[*H. E. Montgomery and E. H. Hill.*]

MR. YOUNG: Even under the present system wouldn't that be a good scheme, to make the mine in some way responsible for the taxes? A. Yes. But the point is, if you levy a poll tax you can get it right away.

MR. MONTGOMERY: And then a man often leaves and gets away without paying.

MR. HILL: A lot of people think these foreigners don't know very much, but they know when they are paying taxes, and you will see hundreds of them leave and go to another town to avoid paying their income tax.

MR. GIBSON: How is that collected? A. The Dome and McIntyre take it off their cheque, but I doubt if that is legal.

Q. And hand it over to the township? A. Yes, but I don't think you can stop a man's money at the mine. You can make out a cheque for that amount and ask him to endorse it. If you are renting a house from the Hollinger, they cannot stop the rent from your pay.

MR. YOUNG: Isn't that poll tax in the township for statute labour only?

MR. MONTGOMERY: There is one solution only, and that is to catch them as they come on. A poll tax could be worked the same as the doctor's fee. When a man comes to the mine the first thing that is charged to him is the doctor's fee, one dollar per month. Well, this could be charged that way.

MR. HILL: The collection of that tax would have to be done from the mine. We ought to have an amendment to the Act requiring the mine to collect it, but under present conditions they cannot.

MR. GIBSON: Is there any sum which represents the assessment of the Hollinger Company for the income tax? A. No.

Q. You do not say "We get from them $14,000 a year and our tax rate is so much, consequently the amount the rate is applied on would be so much?" You don't work back that way? A. No.

Q. Your roll shows the patented claims assessed to the Hollinger Company uniformly at $10 an acre? A. Yes.

Q. And what is the total assessment? A. The total assessment is $40,300.

Q. Including all patented claims? A. Yes.

Q. And all buildings? A. Yes.

Q. Do they pay taxes on $40,300 at the ordinary rate, in addition to their tax under the Mining Tax Act. A. Yes.

Q. What is the value of agricultural land in the neighbourhood? A. It is a pretty hard thing to decide. You get agricultural land here with timber on it, and the timber on it is worth $40 or $50 an acre, but when the timber is cleared off it is not worth $5 an acre.

MR. MONTGOMERY: There is another thing I should have mentioned when speaking of debentures. We have given a by-law for $20,000 a second reading for an extension of waterworks, but until we can place the debentures, they won't be issued either.

Q. You are simply getting ready? A. Yes, just getting ready, and we want to do it as soon as possible, but we have been unable so far to get anybody to take them up. They are all afraid of the north country, unless the government will guarantee it.

MEMORANDUM RESPECTING TAXATION OF MINES

By Mr. P. A. Robbins, Managing Director of the Hollinger Consolidated Gold Mines, Limited, Timmins

The task of appearing before this Commission to discuss taxation of mines is rendered difficult by the fact that it is a Provincial Commission. The matter of taxation is really a national question, because any policy adopted by the Province of Ontario is more than likely to have a decided influence upon Dominion legislation. I therefore feel justified in asking that you grant me time in which to deal with this question upon lines which would be proper if you were a Dominion Commission.

The Function of Gold

Representing as I do, but one branch of mining, namely, gold mining, I shall confine myself to matters affecting that one branch of the industry. A very common mistake is made in assuming that gold is not a necessity in our present day life. We are organized into a complex inter-dependent social family, and anything which secures to us the advantage of civilization is an absolute necessity. A staple basis of exchange is necessary in our life, just as necessary as macadam roads or woollen underwear. The cave-man mode of life required none of these, but we do require them.

Possibly when we arrive at that much dreamed of condition of society when civilization shall have become greater than nationality, when international boundary lines shall have

been erased and when cupidity in human nature shall be no more, then gold may not be a necessity; but until that time we must have some staple, indestructible and uncounterfeitable security and basis of exchange. For thousands of years gold has occupied the position of being internationally and universally acceptable as a medium of commerce, and as a basis of exchange in the fundamental division of labour.

Most business is transacted upon credit, but back of that credit must be the ability to pay, and hence we as a nation build up enormous reserves of gold in order that we may maintain our credit.

It seems incongruous that we should delve in the earth, removing gold from its natural hiding places only to store it again in artificial vaults, but such is the way of the world, and we must go the way of the world unless we seek isolation. Our government demands that banks shall deposit a staple security against their note circulation, not because we consider bankers dishonest, but because we recognize that humanity is frail and that even the sages of finance may fail in their undertakings. In the same way, the world decides upon gold as a standard, and when dealing with us asks to inspect our reserve stocks; hence we mine our gold and store it in vaults.

Before the Franco-Prussian war, Paris and London shared the honours as the world's clearing houses. After the war London alone became the centre of exchange, simply because of England's superior ability to show gold in support of her credit. It may seem superfluous that I should consume time in pointing out well established truisms, but my purpose in so doing is to clear the atmosphere of any suggestion that gold is a luxury and the gold-producing industry is not a necessity. Gold hidden in the ground is of no use to us; produced in marketable form it is a tremendous asset, and its possession will be of the greatest assistance to us in our dealings with other nations after the war.

In considering the taxation of gold mines we should therefore keep in mind that the gold-producing industry is one of the most necessary industries, and our taxation should be designed to place the smallest possible burden upon it.

Why Gold Mining Should be Encouraged

Now, I will ask for a few moments of your time in which to point out the advantages of encouraging gold mining.

The industry is one which will operate at full force at all times in spite of financial depressions. During the period of business depression which immediately preceded the war, there was no place in Canada which was less affected than the little town of Timmins. Its main industry could and did thrive in spite of the general depression. During the five years ending with 1915, the Hollinger and allied companies produced approximately $10,000,000, of which nearly $4,000,000 was spent in the costs of operations, while an additional amount of nearly $3,000,000 was invested in plant and development work. In all some $7,000,000 has been distributed amongst manufacturers, farmers, merchants and workingmen; quite a reasonable sum to come from one little community. With sufficient encouragement, other gold camps will grow. Kirkland Lake is now developing into a mining district of importance, and will be a valuable market for machinery and supplies.

It is only the occasional mine which pays a profit to its owners. In the great majority of cases, the only profit made from a gold mine is the profit made by the manufacturers and merchants who supply the mine with its machinery and other commodities. Hence, it behooves us to encourage in every possible manner, the growth of this depression-proof industry, not alone for the direct benefits to the mine owners, but also because of the benefits to the country at large in the support of the farmer and manufacturer.

As a colonizer, there is no industry so valuable as gold mining. It is the precious metal mining which is building up Northern Ontario. We have the land; we need the settlers, but they are slow in moving in. Given a mining industry, and the country will build itself up at an abnormal rate. In our settlers we want good stock, that their progeny may be strong and healthy men and women. That is exactly the quality of men which the mining industry draws to itself; strong, able men, capable of pioneering, men with ambition, men who can do things.

Hence we should encourage mining, not only for the profits of the industry itself and the benefits to our merchants and manufacturers, but also because of the wonderful colonizing influence of the industry; and of all mining, the gold industry should receive the greatest encouragement, because gold is the lodestone which attracts men most, which inspires them to superhuman effort in overcoming obstacles.

Now, we have many gold deposits of varying grades, a few sufficiently rich to pay a profit; more just rich enough to encourage the owners to keep on working in the hope of making profits, and a great many too low in grade to be worked profitably. By reducing our costs of operation, we are able to work deposits of lowering grade, and hence we should remove every influence which tends to add to the cost of producing gold, in order that the industry may grow to include as many as possible of our low grade deposits.

[*P. A. Robbins.*]

The Present Taxation Law

In regard to the present system of taxation in use in this Province, there can be but little criticism.

There are two defects to which I wish to draw your attention. First: the allowable depreciation upon mining plant. This is fixed at 10 per cent. per annum, which allowance is, generally speaking, insufficient. A fairer basis would be an allowance of 15 or 20 per cent. Second: that while the Act contemplates writing off the investment in plant, no provision is made for writing off the initial cost of development work.

If we sink a shaft we may not write off the cost of the shaft, but we may write off the cost of the headgear which surmounts the shaft, and of the cages which travel in the shaft. If we drive a crosscut, we may write off the cost of the rails and pipe lines which are laid in the crosscut, but we may not write off the cost of the crosscut itself. In the specific case of the Acme mine, before the property reached a profit-making stage there had been expended $100,000 in plant and $200,000 in development work; the Act provides that the plant cost may be charged to operations at the rate of $10,000 per year, but the larger item of development cannot be charged to working costs at all. If, however, the same development work is done in a year of profit-making, it is included as part of the operating costs. This is not logical, and seems contrary to the spirit of the Act.

The Hollinger pays approximately 14 cents per ton to the Province as taxes; this is not excessive, but it might be in the case of a property hovering upon the border between profit and loss. Our system of taxation automatically adjusts itself to these conditions, and does not burden the struggling industry, hence we should adhere to our present method of taxing profits.

The disposal of the taxes is a question which it is to be hoped will receive your attention. At the present time one-third of the Provincial tax goes to the municipality in which the profit-making property is situated. This is insufficient to meet the requirements for roads, schools, waterworks, sewerage plants and other municipal works. A mining town springs into being over night, and requires immediately all the improvements which a farming community would be years in growing up to. Looked at broadly, the Province should not take any taxes out of a new district until that district is out of its swaddling clothes and firmly established. All taxes collected should be expended in the district from which they come, until such time as the district no longer requires the amount collected. Much money is wasted and time lost in providing necessary works, owing to insufficient funds being available for immediately carrying out work of a permanent character Much needless expenditure is made owing to municipal inexperience. The Province should make an investment before demanding a dividend, and it should build up the district before asking the district for a profit.

The Burden of Import Taxes

I wish now to deal with conditions which are beyond the control of the Province, but which particularly affect the gold mining industry.

We are at present engaged in the building of a mill and other plant costing nearly $700,000. Canadian shops are largely unable to take our orders, and hence we are paying directly to the government a tax of 35 per cent. upon the cost of supplies. There is no protection in the tax, because there is no industry to protect. Prices are at abnormal levels, and at the present time the Dominion is taking from us an amount which would equal 50 per cent. of the cost of the plant in normal times.

If we purchase a plant which would normally cost us $100,000, we must pay to the Dominion government a direct tax of $50,000 before we can use the plant in our industry. The import duties which affect us are not fixed at a percentage of normal costs, they are a percentage of the cost at the time of purchase; hence the increased costs of labour and supplies having necessitated a rise in first costs, the import duties have automatically been increased by a like percentage.

Let me give you some specific figures:

In 1914, before the war, we were able to purchase tube mills at a price which landed them in Timmins at a cost of $0.0582 per pound duty paid, the duty amounting to $0.012 per pound. At the present time we are bringing in ten tube mills at a cost of $0.095 per pound, and the duty amounts to 0.023 per pound. The comparative gross figures from this order are:

1916 Landed cost	$41,800 00	Duty	$10,143 00
1914 Landed cost	25,600 00	Duty	5,292 00
Increase	$16,200 00		$4,851 00

[*P. A. Robbins.*]

Take another item of stamp parts:

In 1914 these cost us $0.058 per pound, the duty working out at $0.0111 per pound. In 1916 we are bringing in an equipment of 100 stamps at a landed cost of $0.085 per pound, of which $0.0203 is duty. Upon the whole shipment the gross figures are:—

1916	Landed cost	$51,245 00	Duty	$11,718 17
1914	Landed cost	33,515 00	Duty	6,407 47
	Increase	17,730 00		$5,310 70

These are only two of the many purchases which we are making, but they show how we are being subjected to an abnormal taxation, amounting to an increase of nearly 100 per cent. of the normal tax upon each article. When prices are up, it is the equivalent of the value of gold being down. In other words, when high prices prevail in other industries, the gold industry is depressed, and so we have the peculiar situation of an industry being taxed most heavily when in its most depressed condition. We are to-day paying to the Dominion as a direct result of the war, a super tax collected through the Custom house, amounting to tens of thousands of dollars.

Cannot Protect Gold Mining

Now the gold industry is unique in this respect, for no matter what happens, the value of the product remains fixed at $20.67 per ounce, and we are absolutely unable to raise our selling price to compensate for our higher costs of production.

The manufacturer benefits by an increase in the cost of his imported raw material in this way. Take for instance steel plate, which has a fixed per ton import tax. Now, although the price of plate may advance, the tax remains constant in amount, and hence is a diminishing fraction of the total cost. But the tax upon manufactured articles is a percentage of their value, and hence our manufacturer pays no abnormal tax upon his imported steel plate, while he receives the protection of an abnormal tax placed upon the products of his foreign competitors. The 7½ per cent. super tax modifies this somewhat, but generally speaking, the manufacturer is benefited by an abnormal protection under present war conditions. The farmer is another beneficiary of present conditions; his profits are greater than ever, but in order to lighten his load, the 7½ per cent. super tax is not applied to the implements, twine, fertilizer, etc., which he requires in his business.

Granted that there is no intentional discrimination against the gold mining industry, yet upon analysis of existing conditions we find that a decided discrimination has crept in, and the gold mining industry is to-day paying a heavy indirect war tax, which should be allowed for when dealing with the matter of a direct war tax.

Precious metal mining stands alone as an industry which we cannot assist by a protective tariff; in fact, every bit of protective tariff is an indirect tax upon gold and silver production. We must import our supplies, because they are not obtainable in Canada; and the import tax is our contribution to the protection of other Canadian industries. A protective tariff is of no benefit to our industry, for by no process of taxation can we raise the value of an ounce of gold above its international standard. We can tax an iron mine, and then place a prohibitive import tariff upon foreign iron, which will enable our home producer and manufacturer to raise his prices to a point where his ultimate profit will be but little affected by the imposed tax; in other words, we may impose a tax upon the producer of base metals, and then by a protective tariff place him in a position where he may shoulder the tax on to the ultimate consumer of his product.

Gold Mining a Unique Industry

But not so with gold. A tax upon the gold producer stays with him, he cannot shift or shirk it. By no adjustment of duties can we affect the international value of an ounce of gold. What is the result? If we tax mines regardless of their nature, we throw a double burden upon the gold mine. The iron mine, the copper mine, the cement quarry, the coal mine, all derive the benefit of a protective tariff, which is in effect a bonus paid by the commonwealth to them. They are able to sell their products at prices equal to the cost of foreign products plus the duty and transportation. Now the gold miner has to pay his direct tax, and he also has to pay the tax of the producer of base metals, and the tax of the manufacturer. This is manifestly unfair; it is discriminating taxation.

You may suggest that it would be a good plan to discontinue operations and construction work until the war is over and normal conditions are restored, but here the question of interest arises. While locked up in the ground our gold does no work, it earns no interest, but as soon as it is produced it begins to earn interest. To shut down for two years would be equivalent to a shrinkage of ten or eleven per cent. in the gross values of our ultimate profits, and until the increase in working costs rises to more than this, it pays us to continue.

[P. A. Robbins.]

Under present conditions of labour and supplies, it is really a matter of indifference to us whether we build our plant this year or after the war.

In bringing these matters before you, I have a definite purpose in view, and that purpose is to point out that in dealing with a tax upon mining, it is a mistake to disregard the nature of the mine. Precious metal mining should be treated in a class by itself and burdened with as little taxation as possible. Owing to its spectacular nature, it is a better advertiser than any other industry; it possesses a unique power to attract capital to the country; it is the greatest colonizing pioneer known; it produces vast indirect benefits to the country at large, and it is these lasting benefits which should constitute the profit of the community at large.

If the Province had received no profit tax from the precious metal mines, has it not benefited by the opening up of the country and the growth of the communities served by the Temiskaming and Northern Ontario railway?

In conclusion, I wish to state that my remarks have been prompted by a desire to impress strongly upon you the great desirability of adhering to our present method of fixing the Provincial tax. It is simple, easily understood, and above all it is definite. I have also been somewhat apprehensive that the mistake might be made of singling out the precious metal mines as fit industries for specially high taxation, when it is to the best interest of the country to encourage the search for precious metals by every means at our command, being extremely careful not to do anything which will tend to frighten away the foreign capital required for the development of our vast natural resources.

The question of import taxation has been brought up because it is my belief that apparatus for equipping a gold mine should be admitted free, in order that less capital may be required for opening up gold properties. The gold industry cannot benefit from a protective tariff, and hence should not be burdened by a protective tariff.

Finally, the whole question of taxation, both Provincial and Dominion, is now under consideration, and there can be no doubt that the work of your Commission will have considerable influence in the matter of Dominion as well as Provincial taxation; hence the desire to have the gold-producing industry given the special consideration which its unique nature requires.

Evidence of Mr. P. A. Robbins

(Timmins, 2nd October, 1916)

MR. YOUNG: I assume, Mr. Robbins, the statement you have given us represents your views on the subject with which it deals? A. Yes.

Q. And would you care to add anything by way of explanation? A. The whole gist of the statement is that gold mining on account of its nature should be treated separately from mining of other substances. We have to import our plant, and we are now paying the Dominion government 100 per cent. more than formerly, and gold isn't like other products; its price does not go up with the rest.

Gold Mining Most Heavily Taxed When Least Productive

Q. Your prices are stationary? A. Yes. The price of silver varies, even in times of peace, but the value of gold is absolutely fixed, and gold mining is taxed most heavily when it is in its least productive stage. With regard to the Dominion war tax, I apprehend it will be a permanent tax, and what you as a Commission do will probably guide the Dominion government very much. We are not trying to get away from it at all, and if we have to pay it, all right; but I feel that the Dominion tax is going to be a permanent one.

Q. Have you any idea yet how that tax is going to work out? You have not yet been notified of the amount of your taxation? A. No, but I have figured it out. It figures out about $73,000, as compared with the Province tax of $48,000. That is according to the talk I had with Mr. Breadner. Under the Provincial tax there are certain exemptions; under the Dominion tax there are none. They tax us 3¾ per cent. as against 3 per cent. by the Province. Our tax works out at $47,900 for last year. I don't think that is right, because we are already paying probably between forty and fifty thousand dollars in increased duties.

Q. I suppose that is largely due to the fact that the prices of those goods which you import have gone up? A. Yes. Take, for instance, steel plate. A manufacturer pays a duty of so much per ton. Now, when the price of the raw product goes up, of course he has to pay the additional cost, but his duty is no more. After he has manufactured that plate into something, he is protected by the ordinary 27½ per cent. duty, increased by the rising prices of his raw material. Now, suppose a man makes a boiler, which he is willing to sell at a thousand dollars profit, where he pays only a specific duty on his raw material and is protected by a percentage duty on the manufactured article, he can put his boiler up to a higher price and sell at an actually larger profit than under ordinary condi-

tions. You can put a duty on iron ore, and raise the price of the iron ore by that much. In other words, that is a bounty granted by the commonwealth to the producer of the iron ore. He can increase his price per ton by the amount of the duty, and in that way protect himself. But you cannot protect the gold industry.

Q. You can neither raise nor lower the nominal price of gold? A. No. You can raise the price of gold by lowering the prices of commodities.

Q. That simply comes back to the fact that gold is accepted as the standard, and everything is measured by gold? A. Gold in a free trade country is worth more than gold in a protection country.

Q. That is, if the prices of commodities are lower? A. Well, necessarily they would be; and it is on that basis I argue that gold should be treated as a special industry to be handled in a special way.

Q. As you say here, there is a goodly portion of these matters with which we have no concern on behalf of the Province? A. You have some concern, because they affect one of the Provincial industries. But you cannot regulate them; they are beyond your control.

Q. But it is quite proper that all these considerations should be before us in dealing with the quantum of taxes in the Province? A. Yes.

Q. Now in regard to taxes, have you any criticisms to offer as to the present system of taxation? You prefer the profit system to any other? A. Oh, yes, unqualifiedly. I maintain that the Province has no right to take any taxes out of the district until the district is put on its own feet.

The Question of Depreciation

Q. I was coming to that in a moment. Then there are two difficulties to which you refer here; one is depreciation on mining plant. You think that is too low? A. Yes.

MR. GIBSON: Could you tell us from your experience, what is the life of ordinary mining plant; that is, the machinery? A. Well, it is largely affected by the life of the mine.

Q. But suppose the mine lives longer than the plant? A. Well, of course, your plant will last the life of your mine because you must keep it up.

Q. What do you write off yourself, for plant? A. Well, we write off different amounts. We write it off in lump sums, because there are some things which depreciate more rapidly, as, for instance, cars and drills. You have got to allow 100 per cent. depreciation for those, because they won't last over a year, and some other things like stamp mill parts will last indefinitely. Things like the concentrating tables have to be practically rebuilt in about three years. It is pretty hard to get at an average.

MR. YOUNG: I think in the cost statements we got in England they wrote off 10 per cent. for depreciation of plant.

MR. GIBSON: That is the allowance in the Act. I can quite easily see that different parts of the plant would have a longer or shorter life? A. There is a good deal of temporary plant, which is scrapped after two years' use. We have a number of compressors that we had to scrap, and get air compressors that were more efficient. That plant cost us a fifty per cent. depreciation.

Q. You suggest here 15 per cent.? A. That is based on discussions with Mr. Mickle, the Mine Assessor.

Q. I think there is something in your contention that 10 per cent. would be a minimum, but it would not be possible to have a variable percentage according to the actual wear and tear, because that would be impossible to estimate. You would have to have a fixed percentage? A. Let it stay at ten. If you cannot get it down, don't put any complications in it. That is the beauty of this Act, you know what you are doing. Of course, you might say 2 per cent., or 5 per cent.; if you want to get so much out of the industry, all right. It is a matter of percentage on the plant.

MR. YOUNG: Mr. Mickle gave us some suggestions about that item of depreciation? A. He is the best qualified man in the Province to estimate that, because he has had so many years' actual experience.

MR. GIBSON: You mean writing off for development? A. Yes. My argument is this: suppose you work away on a mine for ten years, and never make a profit. Suddenly you hit some ore which yields a profit. Then you charge off your ten years' of unprofitable work against this. I think that is perfectly right. If you spend all that money in development, and you finally do make a profit, you are entitled to write it off.

Q. One difficulty is that you cannot anticipate in the early stages of a mine what its life is going to be, and if you had to wait until the end of the mine, you would have very little chance to get a tax. The Province needs the money as it goes along, and so does the municipality in which the mine is situated? A. The district needs the money, but the Province can wait until after the development of the district.

Q. What is your concrete suggestion of a remedy? How would you deal with it? A. I would put that development work on the same basis as plant. I think I would call it all plant, but in order to avoid Mr. Mickle's objection, we might say that the cost of development work for two years only previous to the mine making a profit should be written off.

[*P. A. Robbins.*]

Let us take a property making nothing year after year, and then eventually getting something that pays a profit. Mr. Mickle doesn't think we should go back over the whole life of the mine, so we might write off say two years previous to reaching the profit-making stage. That is along the same basis we mentioned the other day; instead of basing the taxes on last year's business, average it over a period of years.

Q. That is where development had been done two or three years previous to the profit-making stage? A. I would allow that to be written off with plant.

Q. Not necessarily to be wholly deducted in the one year? A. Oh, no, same as with plant.

Q. How would you do with the succeeding years where there was a profit, and development work done? A. We would treat those as they are treated now.

Q. The present system has the merit of simplicity? A. Yes. My idea would be to get the Act down to such a concrete form that there would be no room for discussion, and it is pretty near that now. The question of the milling process does not come into the Act, and it cannot very well unless you begin to complicate matters.

Q. But as compared with the ad valorem assessment system you think the present one is preferable? A. Oh, much preferable.

Ontario Tax Just and Equitable

Q. And you think on the whole it is a just and equitable system? A. It is the best working tax I know of. There is no question under it of what you are going to pay, except a few little odds and ends that can be cleaned up without affecting the tax.

Q. The question is more one of the rate than anything else? A. That is all, yes.

MR. YOUNG: You say "if the same development work is done in the year of profit-making it is included as part of the operating costs. That is not logical, and seems contrary to the spirit of the Act." I understand you to mean that it is not logical to allow it in the one case, and disallow it in the others? A. Yes.

Q. You don't mean that treating it as operating costs is illogical? A. No.

Q. It is that the same method is not adopted consistently throughout? A. Yes.

Q. So you are making a sort of concrete suggestion, taking the case of the Acme, that development work for two years previous to the profit-making stage might be treated the same as plant, and charged with the operating costs on a depreciation basis for a number of years? A. Yes.

Q. On a ten, fifteen or twenty per cent. basis? A. Well, it is the general opinion, that ten is not sufficient.

Q. That is an interesting point where you speak of the share that the district should get out of the mining tax. Would you care to amplify it at all? A. I think the district ought to get all the money that comes in the way of taxes until everything is paid for, and of course, a corollary of that would be that after everything is paid for, the Province would get the whole. Leave the district alone until you see what is going to happen. Possibly it hasn't happened yet, but it appears to me that you should give to the town that is growing up suddenly, such as the one here, its waterworks and sewerage system and the various services that are required. Eventually the town gets these, and then towards the end of the life of the mine, it is still going to be drawing in these big taxes, and will not require them. The tax then might possibly better be spent in a new district.

Q. When you use the word "district," in this case you mean the town? A. Well, town or township, as the case may be; the municipality that the mine is in.

Q. We have found some cases in the United States, where that very condition of affairs you speak of has occurred; the local municipality receives far more money by way of taxation from the mines situated within its bounds than it can use to its advantage, and it simply wastes the money? A. That is a condition that is likely to occur under the present system; but at the start I think the town is entitled to all the tax, so that it can get on with all its work in the community. Then it gets the full benefit of it. In other words, the Province foregoes its tax until later, and then takes it when the town doesn't need it.

Q. Can you suggest any scheme that would adapt itself to these circumstances? A. I haven't thought of that.

Q. I have been thinking that over and found it very difficult to suggest any scheme whereby the varying local situations would be met. It would be unwise to throw a large sum of money into the hands of the town when it doesn't need it, even at the beginning? A. That is perfectly true, and there would have to be a Provincial board to deal with it, because the town is inexperienced as a municipality, and it is going to waste money. Now, we have wasted lots of money right here.

Q. The boom spirit and optimistic ideas of a new mining camp might lead to extravagant expenditures? A. Well, you don't always at the start of a town get the best administrators in office. You get men who will talk and impress themselves on a new community, whereas on further examination you find they are not the men you want.

Q. In a time of inflation they might be inclined to spend a little too much for improvements? A. Yes.

[*P. A. Robbins.*]

Q. Then, when you come to the other end of the schedule, when the mine is in its declining years and its revenues are going down, you might find the town still a pretty large one with a good many interests, but hampered by the loss of revenue from the mine? A. Well, that might happen. That is going to happen in Cobalt; and it will happen here sometime, unless we get such a big farming community around that this town can be maintained.

Revenues Scanty in New Mining Towns

MR. GIBSON: The community that prospers by the fact of a mine being located in it should raise a substantial part of the taxes from merchants and tradesmen and others owning property and doing business in it? A. It should, but these men haven't got the money. In the average mining camp the man who comes in comes to make a start. In this town there isn't anybody up to the present who could afford to take the money out of his business. Everybody is struggling along to get on his feet. If there were a lot of established firms with head offices somewhere else, and just their branches here, it would be different; but the business men here are men just getting a start, and they haven't got the money.

Q. And the insurance rate is high? A. Yes; they were paying 10 per cent. in the early days and taxes too.

Q. As a matter of fact, however, the rest of the community ought to bear a share of the taxation? A. Oh, yes. You were asking me if I thought about any way of getting at that. I think as a matter of fact the Hollinger company occupies virtually a sort of government position in this town by underwriting its debentures. We took the waterworks debentures at par. We offered to take the school debentures on a ten-year basis, not at par but to net 7 per cent., and if the government would assume a similar position, the question of debentures could be dealt with by the Railway and Municipal Board. You have a machine there that is ready to handle that phase; then let the Province underwrite these debentures, and it would get its tax as it does now. But I agree that it would be a dangerous thing to have a lot of money thrown into the town, and no restrictions placed on its expenditure.

Q. The town of Timmins is an exception in the fact that you have only got one large prosperous mine. Other towns have a larger number of producing mines, and there is a fairly good source of income from the mining tax; but here you have only one. It is desirable so far as you can secure that result, that the finances of the town should be fairly uniform? A. Yes, that is absolutely necessary.

Q. And if the town begins to depend too largely upon the income from the mine, it would not be uniform. The amount might vary. It might have a profit one year, and no profit the next, and the town's finances might be rather insecure? A. In the case of a mill burning or one of the power company's dams giving way or something of that sort, the town's finances would be crippled for that period, but if the town is put on its feet to begin with, I don't know why it should require such a large amount to be going on with more than any other municipality. Once a town is established and in business, the residents can afford to pay their taxes. Probably 90 per cent of the landowners here who are tax-payers are under the burden of paying for their houses and lots. They are carrying them along, and have either got them mortgaged, or bought them from the townsite company and are still making payments. Now, when that is all paid and is off their hands, they can begin to stand taxes.

Difficult to Operate Variable System

Q. The division in the Tax Act as between the Province and the municipality is one part to the municipality and two parts to the Province. Can you suggest any method of variation that would be practicable as to the proportions, to meet the peculiar situation or difficulties of any town? Would it be practicable to do that? A. You can suggest the first part of it, but it is hard to suggest the winding up part of it. That is, you could say the taxes of the first three years should be given to the municipality; but then, when is the Province going to begin and get its share? That must depend on the situation. I don't know how you can get at that. It would be easy enough to say for the first two or three years that the Province should forego its share of the taxes, and might extend the period at the option of the Railway Board or whatever Commission should handle the matter, and the same authority could decide when the period should end.

Q. My idea was, would it be possible to devise a plan by which a municipality which could be shown to actually need more than one-third should receive more than one-third, and then when that necessity passed and they could do with less than one-third, they should receive less? Wouldn't that introduce a lot of contentious and troublesome matter that would be pretty difficult to handle? A. Yes, it would

MR. YOUNG: You would get away from your simplicity ideals? A. Yes, and then you inject the personal and political element.

Q. Any promising town can dispose of debentures; so that it doesn't require any extraordinary amount of money in the first year of its existence? A. No; it cannot, unless somebody will take them and liquidate the notes It is pretty hard at the present time to do any-

[P. A. Robbins.]

thing up here on account of the fire risk. The school board has had experience of that trouble, and that was why the company suggested we would take the school debentures. There are a lot of things that hang fire in a town. If the town could see its way clear, it could get its schools and waterworks. The school question should have been attended to here eighteen months or two years ago, but want of money prevented it. We spent $2,000 on one building, and probably $1,500 of it will be a dead loss when the new school is ready.

Q. The earliest requirements are water, fire and roads, aren't they, and schools? A. Well, roads, water and schools are about the earliest requirements, and a jail.

Q. Of course, these figures you give us here in the statement are very interesting and very pertinent, but you must not forget that we are dealing with what we hope are abnormal conditions at the present time. Everything has been sent up in price by the war. This Dominion tax was not in existence or spoken of at the time this Commission was formed? A. Well, this tax isn't the super-tax. The super-tax is only part of that.

Q. It is included in this? A. Yes.

Q. Have you got any data as to what is paid by mining companies for taxes in the way of a percentage, in the United States? A. No.

Taxation in South Africa, Minnesota, Michigan

MR. GIBSON: In the South African Union gold mining pays a tax of 10 per cent. on profits. A. Well, there is a condition which is unique. If you took the gold mining out of the country, there wouldn't be anything left. One industry has to bear the whole expense of the country.

Q. That tax is in addition to the customs duties which are paid on goods imported, and things of that kind? A. Yes, that is true. The gold mining industry in the Transvaal has to pay for everything that is done in the country, because there is no other industry.

Q. There are also the diamond mines which pay a very heavy tax? The Premier Diamond Mining Company pays 60 per cent. of its profits to the government? A. Oh, yes, that was more politics That mine was discovered and was sold. I have always considered that it was to block the amount of business.

Q. Was that sold by the old Boer government? A. No, it was since the Boer war. The Premier mine was offered to the DeBeers Company for £100,000, and they turned it down because they didn't appreciate what it was. One man, who had been frozen out of the diamond business, got into this Premier mine, and bade fair to be a competitor of the De Beers people, and for some reason the government confiscated 60 per cent. of the profit, or assumed ownership of 60 per cent. of the stock.

Q. The DeBeers diamond mines pay 10 per cent? A. In my time they paid £147,000 a year, and they were making a profit of two and a half million pounds a year, so that would be about 5 per cent. That South African condition of taxation is one that is likely to be misunderstood, unless you know the country. South Africa and the Transvaal never was anything before the mines were opened, and there isn't anything else there now; no other industry. They import all their raw materials and sell to the mines, and consequently the mines have to pay practically all the taxes.

Q. We had occasion to look into the taxation of mines in Minnesota and Michigan, also in Wisconsin, and we found that in one year in iron mining in Michigan, the companies made a net profit of 25 cents per ton on their ore, and out of that 25 cents they paid 14 cents in taxes. That was an unusually high percentage, but in that case they paid more than 50 per cent. of their profits? A. I think there must be other conditions that are not apparent on the surface.

Q. It was a bad year, the price of iron ore was low, and their expenses could not be reduced in proportion? A. There is another point too. How many of these properties are leased, and leased on the basis of a royalty to the owner? In the Chapin mine, they pay 35 cents a ton to the owner, and another mine I know of there pays 25 cents a ton.

Q. The royalty is of course included in the expenses, but the royalty is taxed as well as the ore? A. Who pays the tax on the royalty, the mining company?

Q. No, the owner of the royalty. A. In the mining company's statement that wouldn't show. They would show the royalty as part of their operating cost. We might lease the Hollinger at $2 a ton royalty, and let the other fellow make what he can out of it. We would be in the same position as the iron companies are in Michigan.

Q. In the end must we not have regard to profit, because that is the only thing that gives a property any value? If it doesn't give a profit, it isn't worth anything? A. That is the beauty of our Act here. We automatically give the Province a tax on the amount of profit we make on our ore. We pay 14 cents a ton on our ore now, but if our ore should drop in value our taxes would drop. I imagine the Tough-Oakes, say, would probably pay a higher tax per ton than we do, because their grade of ore is higher. One thing I would like to be strong on, is, I think the Provincial tax at present is the best kind of tax. The system is equitable, and you cannot better it.

[*P. A. Robbins.*]

MR. YOUNG: What is your idea of the best tax on patented claims that are not being worked? The present tax is two cents an acre to the Province? A. That is a big question. There may be some holders of large acreage, and it might be a hardship to them to pay a 25-cent tax or a 10-cent tax. I think some process by which the claims would revert to the Crown if they were not worked would be the best means of getting them worked. I don't think it is right to tie up mineral lands indefinitely, because you can blanket the whole country in that way. Some corporation, for instance, that is looking ahead can blanket the whole country, until some particular property turns out valuable; in this way they can hold the development up. But I think a man should be given some renewal if he complies with certain requirements.

Q. Do you prefer the leasing system to fee simple? A. From the public and Provincial point of view, I think I do.

Q. What would be the effect on capital? A. That would be the difficulty. The greatest objection to the leasing system in this country is that outside capitalists prefer the fee simple; and we are dependent at present on American capital, while we ought to be dependent on British capital.

2-Cent per Acre Tax

Q. In Cobalt the opinion was in favour of increasing the acreage tax from two cents to something substantial. As a source of revenue it is not very important, but what would be the effect on the mining community provided there was some proper protection to the first prospector? A. Well, except in some cases where companies have tremendous holdings, I don't think it would have any bad effect at all. I had some claims myself which I didn't think were any good, and each year as this little tax bill came in from the Department, I thought a little harder and paid it, but finally I dropped the claims. I didn't think they were worth paying the fee on, but at the same time if I hadn't had to pay a tax, I would have held on to them.

Q. Then, a patented claim pays a local tax as well. In this vicinity they are assessed at $10 an acre; that would be $12 a year on a 40-acre claim? A. That is on the value as farm lands. You might pay a good deal more than that if you happened to be in a farming district.

Q. The Assessment Act provides that a mining claim shall be assessed at not less than the value of agricultural land in the neighbourhood, but all the minerals in the mine and all the buildings necessarily connected with it are exempt from taxation? A. Yes, except those buildings which would be used if it were a farm.

Q. I may say that the Ontario Assessment law is much more lenient with mining companies than that of any of the States we have examined: in most States they assess the improvements, the buildings, the machinery and everything about the mine at its actual value, regardless of the fact that when the mine is exhausted the plant is reduced in value to almost nothing; and then they also assess the minerals? A. That iron mine has got into my mind, making so low a profit and paying so high a percentage of its profits in taxes. Suppose the government turns around and protects them to the extent of about 100 per cent. import duty. If so, naturally, they are going to have this American market to themselves.

Q. You mean for iron ore? A. Yes.

Q. I don't think there is any duty on iron ore going into the States now? A. But they protect them on their manufacture.

Q. But manufacturers wouldn't enter into competition with the iron ore mines? A. Well, I guess the Michigan iron ore business is largely controlled by the manufacturers.

Mr. A. R. Globe, Member of the Town Council, Timmins

MR. YOUNG: Have you anything to add, Mr. Globe, for our information? A. I should like to say a little about taxation from a municipal point of view.

Needs of a New Mining Community

Q. Have you been for some years a member of the town council of Timmins? A. Yes, since the inception of the town; also chairman of the committee on waterworks. I would like to point out the burdens to be carried by a new town; the difficulty of financing and getting things going in a town that springs up overnight. At the present time, there is about $208,000 that we could spend and need to spend, provided we could get it. It is needed to carry on the work of the municipality, and simply because we are located in a mining town, bond houses and financial people won't touch our bonds. Thus, we need $50,000 to complete our waterworks system in order to obtain proper fire protection and maintain the health of the community. We need $35,000 for a public school, later to be followed by a separate school, for which we want $30,000, but I am not counting that. We require $28,000 to clear the bush around

[*P. A. Robbins; A. R. Globe.*]

the town here, which is really not in our municipality; but we must protect ourselves from fire. We need another $20,000 for fire equipment to come at all near what the underwriters require. There is at least $75,000 required for a sewerage system. Now, we know that we are not going to get the money to do all these things, but there they are on the boards; and they are all things that are needed, in addition to the huge sums that we have already spent.

Q. What is your population? I was wondering what your per capita charge would be; it must be very heavy; for 2,400 people, that is about $9 per head? A. We have to take into account so many people outside of our municipality. We are adjacent to a township on one side which is not organized. We have to provide schools for the people there; we have to clean up the bush to protect our own buildings from fire. In the town there are a dozen and one things that all fall on the municipality because we are organized. So also with the townships on both sides of us; we have to provide a great deal for them. They have no fire protection, but we cannot stand by and see other fellows' houses burn down; if we do, our own will be set on fire. We have to go over and help them. We supply water to them from our reservoirs in order to keep their wells shut up. A few years ago in Cobalt they had an epidemic of typhoid fever that cost the town a great many lives, because they had no waterworks system; they had no sewage disposal. We have got past that here so far as water is concerned; we got the waterworks system in in 1914, and the result has been that the deaths from typhoid fever have been practically nil. But we have been getting the short end of the stick in this district as regards taxation. Now, take Cobalt; they have been getting 50 per cent., and our expenses are just the same. In discussing our finances with some of the other men about town we feel that we should get at least one-half, the same as Cobalt, and if the government does not feel disposed to do that, they should come forward and guarantee our bonds so as at least to make them saleable, because they know what our standing is, and financial houses will not take our word for it.

Q. Well, do you think the 50 per cent. should be continued after the town has got organized, and got its preliminary requirements satisfied? A. After the town has got well on its feet then there might be a re-adjustment, but for a time, in order to get started, we certainly need the larger proportion. In this end of the camp, up until last year, the Province had done practically nothing. Last year they spent a small amount on roads and this year they spent a little, but up until last year there was absolutely nothing done by the Province in this end of the camp.

MR. GIBSON: Would there not be difficulty in effecting the readjustment you speak of, Mr. Globe? The community would always have expenditures in view, probably legitimate enough, and it might be difficult to convince them that the time had arrived when they should relinquish a part of the 50 per cent.? A. There might be some difficulty in that direction; but to overcome it, the government might have and probably would have a department that would look into the resources and requirements of the municipality when guaranteeing its bonds and making them saleable. That is what we have been trying to do; to get some money to finish up our waterworks and build our schools. If we fail in that, we have to go elsewhere to sell these bonds.

Difficulty in Selling Bonds

MR. YOUNG: If the bonds were guaranteed, a smaller interest rate would be sufficient? A. Yes.

MR. GIBSON: Isn't the chief difficulty in disposing of your bonds the fact that peopl*e* fear the stability of a mining camp? A. Yes.

Q. If you spread your bonds over fifteen or twenty years, few people would like to touch them? A. If our bonds were guaranteed by the government we could sell at thirty years.

Q. The government would have to take into consideration the same facts that the investor takes, and if they guarantee your bonds, they become liable for them? A. Well, they have a department and the machinery to investigate and find out.

Q. I don't know how you are going to find out how long a mining camp will last. The government are not infallible, and cannot see into the future any more than other people. They can ascertain what your standing is, but to ascertain the life of the camp is venturing upon prophecy? A. Well, I cannot say that. They have a very clear cut policy, and they know fairly well how long we will be working, and when you spread bond repayments over a large number of years they become very much smaller. Take $35,000 school debentures, say for ten years; it means we would have to raise $4,500 a year; whereas for thirty years it would be about $2,000 a year.

Q. At any rate, you regard the law at present as to your share of the taxation of the mines, as very useful to the community? A. Oh, decidedly.

Q. You would not like to relinquish any part of that? A. No.

MR. YOUNG: Is any amount enough to give to a mining camp springing up in a community that is wholly unsettled? A. In this camp on January 1st, 1912, there were about three buildings. In four and a half years it has grown to what you see now.

[*A. R. Globe.*]

MR. GIBSON: A town of this kind situated in a mining neighbourhood has almost necessarily a rapid growth? A. Yes.

Q. It is not the same as an agricultural country where the settlement is more or less gradual, and where the growth of the towns and villages is also gradual. You must have everything at once in order to meet your requirements, and that necessitates large expenditures in the initial stages of the town? A. Yes. This is probably one of the first camps that shows a permanent mining industry.

Q. You mean in Ontario? A. Well, on a par with Johannesburg or Kimberley or some such mining centre as that.

Q. Would you draw a comparison between the gold mining industry in Porcupine and Johannesburg? A. I think I would.

Mr. J. P. McLaughlin, Merchant and Member of Town Council, Timmins

MR. YOUNG: What can you tell us, Mr. McLaughlin? A. I came for the same purpose that Mr. Robbins and Mr. Globe came for, but I think they have pretty well covered the point I wished to speak on. They both went into it very thoroughly, and I think you have grasped our point of view very well. I don't see the use of me going into it any further. I am on the town council, and we do experience the difficulties that Mr. Globe brought to your attention in financing a town that has sprung up in so short a time. So many things required as quickly as we can possibly get them, schools and so on, make it very difficult to finance when we cannot sell our debentures. In fact, had it not been for the generosity of the directors of the Hollinger mines in taking our debentures for our waterworks, it would have been impossible to sell them. Now, as to the insurance rate: We paid 10 per cent. until a short time ago, and now it is 7, and there is no merchandise house that can afford to keep covered. You may say, if your business doesn't pay, get out of business. Well, we would all have to get out of business. We could never pay 7 per cent. and carry 75 or 80 per cent. insurance. There isn't a business in the town would stand it. Our costs of doing business are naturally higher than in old Ontario, and we have to pay much higher wages and freight rates and express; we also have to carry bigger stocks, and have to compete practically with the departmental stores in the city, which we cannot do and pay the high insurance rate. We must have funds for better fire protection; that is the point I am trying to make. It is really the most important thing for a town, fire protection.

MR. GIBSON: Your high rates of insurance, however, are not due to the fact that you are a mining camp, but that you are in a timbered country? A. Yes; and besides the buildings are mostly of lumber.

Q. And naturally all these northern towns are just as liable to conflagrations as Timmins, so it is not the fact of your being situated in a mining district that makes the rate of insurance high? A. No, the same applies to the other towns in the northern districts. Still the selling of our debentures is affected by the fact that this is a mining camp.

Mr. W. J. Wilson, Mayor of Timmins

MR. YOUNG: Would you like to add anything, Mr. Wilson? A. I think the town should get more assistance in the early stages. I have been mayor for some years, and I know before we got the money for the waterworks, we were taking the water from Miller lake and other places, and we would have been all dead in this community if we had not got the waterworks. Over $100,000 this town had to spend in the first two years of its existence, and, of course, we had to clean up the trees. It takes a lot of money to supply the needs of a town that grows so rapidly as this has done. People are complaining that we have not laid sidewalks on all the streets; and sewerage has got to be attended to. It is only a question of time when the ground is going to be contaminated with the cess pools, so I think the government ought to come to our assistance and give us at least one-half the royalty, if not all of it, for five or ten years.

Mr. W. H. Wilson, Clerk of the Township of Tisdale, South Porcupine

MR. YOUNG: You are the township clerk of the township of Tisdale? A. Yes.

Q. Do you hold any other office? A. Treasurer

Q. The present population of the township is about 4,000? A. Yes.

Q Well, it is less than it was, isn't it? A. It has stayed pretty much about the same figure for the last three or four years. There has been a growth around Schumacher which compensates for losses elsewhere.

Q. You have not given us the amount of your debenture debt? A. The government debenture debt is $36,000 and $4,500 for a fire pump.

[*A R. Globe; J P McLaughlin; W. H. Wilson.*]

Q. When do the debentures mature? A. The government debenture runs ten years There is one instalment paid on that: the next instalment is due on the 1st of May, 1917.

Q. When does it run out? A. 1926.

Q. The instalment is for the same amount in each year? A. Exactly.

Q. What is this $4,500; how long has it to run? A. Two years. One instalment comes due this week; and one instalment twelve months from now, October, 1917.

Q. Are you contemplating any further issue? A. We are, for schools.

Q. How much would it be for? A $30,000.

Q. For ten years? A. 15.

Q. What rate of interest, five? A. Six per cent.

Q. Have you passed your by-laws yet? Are you going to get this out this year? A. I don't know. We are trying to find a market for them at present.

Q. What is your school accommodation now? A. We have four schools; one at South Porcupine, one at Dome mines, one at Schumacher, and one at Moneta.

Q. And where do you propose to spend the $30,000 for the schools? A. Well, the Schumacher school is very inadequate, and South Porcupine; we will possibly put up one large school which would accommodate both the Dome and South Porcupine school children. Of course, these plans are not down to a definite point yet.

Taxation of Mining Claims

Q. How do you tax mining claims in the township of Tisdale that are not producing and not being worked? How do you assess them? $10 an acre? A. Well, they have been assessed probably at an average of $10, $15 or $20 an acre in the past; but this year the township has changed the assessment according to the concessions in which the property lay. The first three concessions are highest, being nearest to roads and railways; they are put down at $35 an acre.

Q. Regardless of whether they are cleared or uncleared? A. Yes, a uniform assessment.

Q. And concession 4? A. $30 an acre.

Q. Concession 5? A. $25 an acre.

Q. Concession 6? A. $20 an acre.

Q. Would the lands bring that in cash if they were sold? A. Some of them would. It depends on how much the owners needed the money.

Q. Is that a fair value? A. I don't know I could not express an opinion on that point.

Q. $35 an acre for uncleared lands in that township; were there any roads or anything else in the way of improvements that made you put the value at that high figure? A. Well, it is not for me to say. We have four settlements or towns to look after. They require, more or less, street lights, sidewalks, fire protection, etc. These things are really needed. Mr. Globe pointed out that fire protection at Moneta and Gillies Lake was supplied by Timmins. At present we have no organized fire protection. We depend on our good friends in Timmins.

Q. Now, mining claims in the vicinity of Timmins would be in the $35 class, would they? A. Yes, I think in the second concession.

Q. And you would make no distinction between mining claims and arable land, I suppose? A. There isn't much arable land in the township that is under cultivation. It is practically all assessed as mining.

Q. Have the lands been all taken up as mining claims? Yes, and as veteran claims.

Q. The veteran claims don't come in? A They are assessed as mining claims.

Q. They are not available for school taxes? A Oh, yes.

Q How do you find your collections? A Of taxes?

Q. Yes. A. Well, they are not a hundred per cent. by a long way.

Q. What percentage of uncollected taxes do you allow? A. Generally we allow 20 to 25 per cent. each year.

Q. I hear you have a poll tax in the township? A Yes, we have. It has been in existence since 1914.

Q. What is it? A. $2 per head.

Q. That is in lieu of statute labour? A. Yes.

Q. How do you get that? A. The collection of the income tax was not satisfactory, because of the floating nature of the population.

Q. Are your income tax payers very largely mining employees? A. Very largely. They were in 1912 and 1913 changing around very much; they would be assessed in the spring, and when you went around after the income tax they were not there. I would say roughly that for about 90 per cent. of the income assessment these two years, we didn't know where the men were at all. That was before the poll tax was levied.

Q. And do you find the poll tax more satisfactory than the income tax? A. Much more satisfactory. The money is collected, most of it, in the early part of the year.

Q. Do you get that from the man himself or have you an arrangement with the mining company? A. In many cases it is from the man himself, but most of it comes from the mines.

[*W. H. Wilson.*]

Q. What percentage do you think, roughly, of the taxes for 1916, would be paid by employees of the mines? A. I don't know. I could not tell you just offhand. I think there are some pretty heavy income taxes from the mining men holding the higher positions. I think I am safe in saying over 30 per cent. would be income tax. The big percentage is in the residential townsites.

MR. GIBSON: Have you anything at all of a farming population in your township? A. Practically nothing. There is one man cultivating some land just outside of South Porcupine. He is getting good crops, but I don't know what his acreage is.

Q. Then, practically everything depends upon the mines? A. That is practically the case.

Q. But there is good land in the township, isn't there, more or less? A. There is, but it would cost a lot to clear it.

Q. But the land is there and it could be cleared up? A. Yes, and the soil is good. Outside the town we cleared two acres, and it cost us $200.

MR. YOUNG: The assessments on mining properties strike one as rather high in view of their exemption? A. This year the amount is almost double that of last year.

Q. What do you assess in the way of mining buildings? A. I could not tell you. It is laid down.

Q. You followed the Assessment Act, I suppose? A. Yes. The assessment of mining companies is composed of their offices, residences, club houses and buildings of that kind.

Q. Any buildings not required for the working of the mine or sorting? A. Yes, but not including concentrators.

Q. I believe in Cobalt there are certain portions of the mill which have been assessed, and on appeal to the judge at a court of revision the assessments have been sustained. In other words, the local judge has decided that the word ''concentrators'' used in the Act refers only to concentrators as such, and not to the whole mill building and machinery. However, in the township of Tisdale the mills have never been assessed? A. The assessor stays very closely to the Act.

MR. GIBSON: Are the buildings assessed at the cash value? A. Generally 75 per cent. The Dome company has supplied the assessor this year with the exact cost of its buildings.

Mr. Gordon H. Gauthier, Solicitor for the Township of Tisdale, Porcupine

MR. YOUNG: Can you give us any further informatino, Mr. Gauthier? A. There were one or two items that I heard discussed, and have noted down. First of all, in connection with the 2-cent per acre tax on mining lands in the unorganized districts. I don't think there is any question but that should be very much higher. My experience has been that it is not large enough to prevent the holding of these mining claims, once they are patented, practically indefinitely; and I would think that 99 per cent. of the claims outside of this camp, in Gowganda, for instance, and in all other mining parts, for which patent has issued practically fall into disuse. No attempt is made to develop them; there is no possibility for a prospector to get in and prospect them, and it does seem that if the tax is levied with the idea of bringing these claims back eventually, so that they can be developed by other people who are willing to develop them, the tax should be very much larger.

MR. YOUNG: What would you suggest? A. I think $10 per claim per annum would be a reasonable tax. There is this in connection with the Tisdale mining claims which might be material. In years prior to 1916 the average assessment was about $20 an acre and the tax levied about $24 per annum per claim. We have found that practically all the taxes levied by the township have been paid. The first tax sale for the township of Tisdale has been advertised for this year. You understand that taxes have to be in arrears three years before the lands are sold for taxes, so this has been the first year it has been possible to sell, and I asked Mr. Wilson to make a memorandum before we came out. Out of the total mining lands in the township, there is only $40,000 worth advertised for tax sale.

Q. How many acres would that be? A. If you estimate it at $20 an acre, it would be about 2,000 acres. So you see that even the assessment on the basis of $20 an acre does not prevent most of these lands being held and taxes paid on them.

Q. Nor, I suppose, is the Tax Act an inducement to the owners to develop their lands? A. No, that is true; that seems to be the situation. The difficulty seems to be that on many of these claims companies are organized during the rush times; stock is sold; they do a little work on the claim and exhaust the money in the treasury. The stock becomes unsaleable; the company is defunct, and nobody has any interest in further development. No one can prospect the claims, at least they are still held so that a prospector is not able to file on them, and the result is they will lie years and years without any attempt being made to develop them.

Q. The argument is made before us that if you impose a large acreage tax it would act as pressure upon the owners of undeveloped mining lands to develop them? A. I don't believe it would, but it would certainly throw them open, so that other people could acquire

them and develop them Even though it would not force the original owner to do something with them, it might put the lands into the hands of people who really intended to work them.

Q. Do you think it would work hardship on the prospector, or any one, to increase the acreage tax in the unorganized districts? A. It possibly would on the individual prospector who holds the claims; but my experience is that of all the claims in the Porcupine mining district not more than one-tenth are held by prospectors. Any increase in the acreage tax would hit the prospector harder, but, on the other hand, it would throw land open for the same prospector to prospect that he cannot get on at all now.

Q. Someone suggested that it would be hard to find a prospector that would be affected by a 25-cent tax. Would it help the prospector not to apply the tax for a certain number of years? A. I don't think I know of any prospector in this country who cannot afford to pay a $10 tax per claim. No doubt there would be some objectors, but the position is that there would be other lands thrown open to them.

Municipality Should Have Larger Share

Q. Is there any other thing that from your experience as Mining Recorder you would regard as material? A. The share of the tax for municipalities does not seem to be quite enough. Municipalities are allowed one-third of the mining tax levied, which is a thirty-mill income tax. That allows the municipalities only 10 mills as its tax. The law limits the municipalities in taxing the income of mining companies to this.

Q. You mean that otherwise they would be assessed on their business assessment or on their income? A. Yes, and it would be at the thirty-mill rate.

Q. Would you take that in lieu of the one-third? A. We are forced to take one-third

Q. But would you take the converse of that? A. Yes, I think so. I think the income under the Assessment Act is arrived at exactly the same way as it is arrived at by the Mining Assessor. It is net income after all costs.

Q. In that connection, Mr. Gauthier, do you go through the form of assessing any of the mining companies at all on your books? A. They are entered on the books

Q. I mean in regard to the mining tax, not as to land? A. They are assessed on the township books for income tax, and instead of the mine being assessed, the amount to be entered is ascertained from the Mine Assessor.

Q. You don't go through the form of working out the assessment? A. No, we rely on the Mine Assessor.

Q. In Cobalt they go through that form? A. Yes, and I imagine it is the proper thing.

Q. And in Coleman they do, and they strike a 10 per cent. rate in order that they may get their one-third income tax from the mine? A. Well, our practice is to leave it that way, and just collect the one-third tax There can be no question, as the gentlemen who preceded me pointed out, that the municipalities should get a larger share of the tax. I think you appreciate the situation exactly. Very large outlays have to be met by the municipalities, and it is absolutely impossible to sell our securities.

Q. You will be satisfied if you get a little more from the mines? A. No, but it would help. There is another point that occurs to me, and that is the fact that in the new townsites one-quarter of the lots have to be turned over to the government, and until sold they are untaxable as Crown lands That means in these new municipalities three-quarters of the land has to meet large expenditures, without any assistance from the government.

Q. That, of course, is not applicable solely to mining districts? A. No, to all districts. We have been up against that proposition in the township of Whitney, of which I am solicitor. In that case the government has a quarter interest in the Porcupine townsite, and for one or two years the owners of the townsite claimed that they were government lands. There was no revenue at all from the government townsite; afterwards, the township confirmed the assessment of a three-quarter interest in the lands, and since that time the lands have been paying so much of the taxes. I don't know when Cobalt was given its half share in the tax instead of one-third.

Q. At the outset. A. As a special consideration. But I have always felt that while they had problems in Cobalt, they had no better claim to that consideration than the municipalities in Porcupine camp.

Mr. A. D. Miles, President Canadian Copper Company, Copper Cliff

(Toronto, 22nd December, 1916)

CHAIRMAN: Mr. Miles, we would like your ideas on the subject of taxation. I daresay you know we have had evidence and opinions from the Mond Nickel Company and others, in the form of memoranda which will be published, and we were wondering whether you would like to give us your opinions or any ideas you have on the matter for publication? A. Briefly, the mining tax of Ontario is a tax of 3 per cent. on the excess of annual profits above the sum of ten thousand dollars ($10,000.00). These annual profits shall be the actual market value of

the output at the pit's mouth less certain deductions which should not exceed one-third of the total amount. I believe this mining tax on profits has been in force since 1907 and has yielded, to the end of 1914, about one million dollars ($1,000,000.00), of which amount the Canadian Copper Company has paid a little over twenty per cent. Twenty-seven (27) companies contributed in 1914. Next to agriculture, mining is Ontario's basic industry, and as such should be encouraged by the government. Agriculture has always received favourable treatment from the government, and has never been subject to a tax with the exception of the present Provincial war tax. The mining industry has always been willing to pay its share of the necessary taxes of the Province, and has never made objection to the present Mining Tax Act, which is considered fair and reasonable. The tax is a tax on profits, and as such does not work a hardship on the mine in the development stage. Suggestions have been put forward that the tax should be on ore reserves instead of profits, but this would have a very harmful effect on the mining industry. It would cause the operating companies to cease developing ahead of their demands, and would mean that in times of national emergency, such as the present, the production could not be materially increased. Broadly, I think the Ontario Act is the best of any which are in operation.

MR. YOUNG: What do you mean by the best? For the mine? A. No, it is the most equitable.

Q. You think it is the best method of taxation? A. I do.

Q. For the community and the mine owners? A. Yes, there is bound to be difficulty in arriving at the value of the ore at the pit's mouth. For example, in this article in the *Globe*, if you figure the taxation as they have shown it, you value the ore at about $28.00 per ton.

MR. GIBSON: That you regard as preposterous? A. Quite excessive.

MR. YOUNG: I may remind you that your company has supplied a good deal of information and material at different times to the Mine Assessor on this subject of taxation that will be available to us, and I fancy that what the Chairman has in mind is whether you would like to add to that or supplement it, or whether we might accept it as representing the views of the company. We want to give consideration to the question from all points of view. A. I have not been over it recently with Mr. Mickle, but I have been over it often in the past. His method of arriving at the division of profits is sound, and in the main I agree with him

Q. There is nothing further that you desire to add to the information that has already been furnished to us from different sources? A. No, I don't think so.

MR. GIBSON: The system that has been acted upon in connection with the taxes, you think would be a fair and proper system? A. I do.

Q As a standard and permanent arrangement? A I do think so, yes.

TAXATION OF MINING COMPANIES AS AFFECTING THE MOND NICKEL COMPANY, LIMITED

(MEMORANDUM NO. V. FROM THE MOND NICKEL COMPANY, DATED 27TH SEPT., 1915)

Bearing of General Conditions on Taxation

The entire question of incidence of taxation is one of extreme complexity. That this is true, is shown by the great divergence of opinions on the subject. Taxation may take so many forms, and the benefits derived from the expenditure of public money may be so obscure, that there is little wonder that the subject bristles with difficulties, and that there exists so great a conflict of opinions. In spite of this conflict, however, there are certain principles whose justice is so obvious as to meet with the approval of almost every one who gives serious thought to the matter. Among these, probably no principle receives wider acceptance than the general statement that, other things being equal, the incidence of taxation should bear some relation to, and the amount of taxation should as far as possible be proportionate to, the benefits derived therefrom.

This principle is unconsciously recognized in a variety of ways. If one's premises are benefited by a concrete walk built by the municipality in which he resides, one has to meet a frontage tax. The entire levy of local taxation for school support and for municipal purposes is a further recognition of the same principle. But the application of the principle, which is seen to be so obviously just when these smaller areas are under consideration, appears to be nearly, if not quite, overlooked when larger areas of our Province are dealt with.

While no larger legal divisions of our Province than municipalities are recognized, yet, leaving aside any possibly smaller natural divisions, all recognize the great difference in development, natural resources, industry and even climate, between the northern and the southern parts of Ontario. So marked has been this recognition, that some have even gone so far as to demand that the Province be subdivided into two.

[*A. D Miles: Mond Nickel Company*]

Where so clearly marked and generally recognized a distinction exists, it surely should receive recognition when the incidence and amount of taxation are under consideration.

In order to illustrate this most clearly, let us consider at some length the relative advantages, from the point of view of development of the district where located, of two industries—one, a manufacturing industry located at one of our larger business centres, let us say at Toronto, at Hamilton or at St. Catharines; and the other, a mining and smelting industry located in one or more of the comparatively wild and undeveloped districts of northern Ontario.

In the former case, capital expense will be mainly for the purchase of site, for construction and equipment of plant and for negotiating and making connections with existing telephone, telegraph, railway and Hydro-Electric power lines, public roads, and municipal water and drainage systems. Contractors as well as materials for construction are commonly close at hand and quickly available, so that generally the entire work can be quickly rushed to completion and the loss of unproductive capital reduced to a minimum. In most cases, the workmen for operation will be near at hand and will come from existing houses, their children will attend existing schools, and the entertainment of their families will be taken care of by existing institutions. All will have the advantage of existing streets, fire protection, police, shops and the many other utilities of a developed community.

In very many instances the municipality in which the industry is located will go so far as to remit the municipal taxes for a number of years, if indeed it does not actually bonus the industry, so highly is the mutual benefit regarded.

No sound objection can be raised against such an application of the principle above stated, that an industry located with all these advantages should pay liberally in taxes for them.

Pioneer Companies Must Provide Public Utilities

Let us contrast with this the case of a pioneer company establishing a mining and smelting industry in the northern part of our Province. It will be the exception, and not the rule, if it has not to construct several miles of difficult road before its property can be reached at all. Cheap temporary boarding-houses must then be hastily constructed, and a minimum of supplies and men rushed in at very heavy teaming expense, until a railway can be constructed to the property from the nearest existing railway line. While the development of the mine and construction of the plant are proceeding, a village site must be secured and a village built for the workmen, with a school and stores; fire, water and drainage systems must be constructed, and some forms of entertainment for the new community provided. If requirement for power is large, one or more water powers must, if possible, be acquired and developed, and many miles of transmission and telephone lines built. If a municipality already exists or is later formed, the company will have to pay practically all the municipal taxes. In addition to all this work at each of its mines, in the case of smelting ores such as the nickel-copper ores of Sudbury district, a still larger outlay must be made for similar necessities in connection with a reduction works. In all this, the capital outlay is very large, the time of unproductive waiting is very long, and the risk is very great (as is shown by the large number of failures compared with the small number of successes).

In presenting all these facts, we do not wish to be understood as raising any complaint against the conditions. We merely wish to make clear the enormous difference between the two cases with respect to expenditure of capital that must be made, owing to the difference in the state of development of the parts of the Province where the two industries are respectively located, and to urge that the incidence and amount of taxation in the two cases should in justice bear some relation to this difference. From the point of view of taxation, these expenditures are already in large part a form of tax, as will appear more fully below.

In order to impart a more real conception of this matter we give, briefly, the amount of these expenditures already borne by the Mond Nickel Company. This amount is constantly increasing:

For railways required to reach its mines only (exclusive of those at its reduction works, which though costing over $150,000, may be regarded as industrial tracks)	$180,000 00
For roads to properties, approximately	10,000 00
For village sites, villages, water systems, schools and other public buildings..	350,000 00
For water power acquirement and development	840,000 00
For transmission and telephone lines	180,000 00
Total...	$1,560,000 00

The railways are used by the company's employees and by others, and are thus a means of opening up the country generally. When the mines are worked out, most of these railways and all the roads constructed will remain as permanent improvements.

[*Mond Nickel Company.*]

The water-power sites are merely leased from the government and according to the terms of the lease, the permanent improvements, dams, buildings, etc., which usually amount to over 75 per cent. of the total cost of development, must ultimately revert to the Crown, and may under certain conditions revert at any time. In the meantime, a moderate rental is paid for power used.

These figures will serve to make clear the very great difference in cost between establishing an industry in the undeveloped part of our Province, and establishing an industry in the more developed parts, where full use can be made of existing public utilities. The greater part of the above capital expenditure has been undertaken by the company, solely because of the undeveloped state of the country in which the industry is located, and much of the improvements effected will remain as permanent development of the country when the given mines are worked out, and will have opened up the district and have made outlying parts more accessible for every one in the meantime.

Nor does the handicap cease when capital expenditure is completed and operation begun. The same less developed state of the country is the cause of increased costs in almost every direction, but principally in that of labour Even such public necessities as a customs house, schools, police station, etc., must be met by the company, who must also defray the cost of policing the community in whole or in part.

We do not maintain that every dollar of this expenditure, capital and current, is the exact equivalent of a dollar in taxes, but we do hold that, if the above generally recognized principle of taxation is admitted, *viz.*, that taxation should be in some kind of proportion to benefits derived therefrom, a very large allowance must in justice be made for expenditures of the above nature and amount, when the fixing of the tax burden is under consideration.

Purchase Cost of Mining Properties in Relation to Taxation

If, contra to this view, it is contended that one of the principal public benefits to a mining company consists in the ore itself, we are compelled to ask whether, if this view is taken, the government should not then grant the ores only to operating companies, in place of permitting valuable ore bodies to be held by speculators, who take toll of operating companies, to the extent of very large sums of money. We do not necessarily hold the view that this policy is advisable, but we do maintain that, if speculators, who merely hold up properties from being worked, in order to extort large sums from those who are willing to put money into their development, are allowed this privilege, then the operating companies, in being compelled to pay these heavy purchase prices, have already expended large sums of money which, from their business point of view must be regarded by them as equivalent to a heavy royalty or tax on this ore

These speculators have been allowed by the government to tie up valuable ore deposits for years By doing so they prevent operating companies benefiting the community and the Province by the expenditure of money on exploration, development and operation. The sole benefit is to the speculator who pays almost no taxes, spends no money in developing the country or his property, retards the growth of the country, and, though undertaking almost no risk whatever, is allowed to enrich himself by these means.

The government, by permitting these properties to be alienated without any restriction as to time of development or operation, and without any tax sufficient to compel operation within reasonable time, has, without intending to do so, already diverted the equivalent of a large tax or royalty to the pockets of private individuals. Does it seem legitimate and just that, having allowed this, the government should disregard this fact entirely when the proper incidence and amount of taxation is being considered?

We submit that these conditions are not only an injustice to the industry but also to the Province; also that these conditions and this attitude, unintentionally, tend to discourage the mining industry.

We fully realize the difficulty in creating and maintaining an interest in prospecting, and have no desire to criticize in any way the means by which the government endeavours to secure this interest. We merely wish to call attention to a condition that has cost the Mond Nickel Company large sums of money in securing its ore supply, and to point out clearly that this condition, for which the company was in no way responsible, has resulted in necessitating these payments, which, from their point of view, are the equivalent of a heavy royalty or tax. We also believe that this fact should receive consideration, when further taxation is under consideration.

Taxes Now Paid

While submitting the above discussion as to the just incidence of taxation in general, we wish to indicate briefly, in addition, the taxes in various forms, already being met in Canada by the Mond Nickel Company. These for the current year (1915) are as follows:—

I. Dominion Taxation (Customs).	
(a) Average duties hitherto paid	$25,000 00
(b) Estimated increase due to Dominion War Tax	25,000 00
II. Provincial Taxation:	
(a) Provincial Income Tax after allowing for Municipal benefits	4,000 00
(b) Provincial War Tax, estimated at	1,000 00
(c) Workmen's Compensation already paid, $30,760.00 with later adjustment, probably	35,000 00
III. Municipal Taxation	9,000 00
Present annual total	$99,000 00

The company has also to pay the very heavy special war taxes now imposed in Great Britain.

Already, increase in Dominion and Provincial taxation and in freights due to the war, and increase in Workmen's Compensation are costing the company over $100,000 annually, and a further rise in freight rates has been requested by the railway companies and is receiving the attention of the Railway Board.

It is just over a year since mining companies had to face the 8-hour law. This year they had to pay a large sum for the first time to Workmen's Compensation. With all these increases in the cost of operation within less than a year and a half, most of which are directly the result of new legislation, and with the present further investigation into their business, which threatens a further heavy financial burden of taxation, if indeed practical confiscation of their property has not to be faced because of compulsory refining under uneconomic conditions, can it be wondered at that British investors, who have already poured millions of dollars into the development of the country, only to meet at every turn with what must impress them as a feeling of hostility in place of assistance, should already be seriously considering the question of looking elsewhere for their supply of ore? This attitude of the government of Ontario is beyond the understanding of the British investor, who can with reasonable safety invest his money in the mines of South Africa, of Australia or of Tasmania. To us, the repeated investigations to which the mining industry and in particular the nickel-producing industry is subjected, seem little less than suicidal, unless there exists a deliberate purpose to injure or kill the industry, a result we feel not to be intended.

It may be held that the above amount of Provincial tax is very small. To this possible objection, we wish to reply that this is due to the current condition of the company and to the wording of the Mining Tax Act. The Mond Nickel Company has been for some years a very rapidly expanding company, and has spent annually very large sums on development and other charges, which, in accordance with the Act, must be taken from the value of the ore at the pit's mouth, for the year in which the expenditure is incurred. Naturally, this has caused heavy deductions from assessable ore value, that with the company become deferred charges. This, of course, will react in the opposite direction later on

Just Method of Assessing Sulphide Ores

No tax based on ore value can be justly levied on annual profits, since this becomes a tax rather on superior skill than on ore. Any just assessment of ore value for smelting ores, must be based on both the recoverable metal contents of the ores and on the chemical composition of the ores in relation to cost of fluxing, since, otherwise, the company with lower grade ores, of a composition requiring high cost of fluxing, will be relatively most unjustly taxed.

This apparently complex, but really quite simple matter, can best be made clear in verbal discussion.

Investment, History and Profits of the Company

We wish respectfully to draw attention to a further matter in this connection. The press has several times given a grossly exaggerated idea of "huge profits" made by the Mond Nickel Company. While we do not for a moment believe that this idea is held by those in authority, yet we feel that we ought in justice to the company state the following facts:

[*Mond Nickel Company.*]

The discovery of nickel carbonyl, the volatile compound on the formation of which the Mond process for refining nickel is based, was made in Dr. Mond's laboratory in 1889, from which time the development of the process may be dated.

From this date to about the year 1900, the development of the process from a laboratory experiment to a commercial operation was continued with large incidental expenditure of capital. Operation on a commercial scale was begun in the year 1900, so that a period of 26 years has been required to develop the business to its present status. Of this period 11 years was consumed in development of the process, and 15 years in commercial operation and gradual extension of operation and market.

At the present time the company has an actual existing investment (not merely on paper) of approximately $14,000,000, of which approximately one-half is invested in Ontario.

The total profits earned during this period up to the end of their financial year (April 30th, 1914) amounted to less than $6,450,000. The total dividends paid were, of course, much less than this amount. From these figures it will be evident that the company, which expended in Canada during the year 1914 alone, upwards of $3,788,000, cannot be justly accused of making unwarrantable profits. In this connection we would welcome a comparison with the more successful mining companies in Cobalt and Porcupine, as to amount of investment in Ontario, as to relative amount of annual profits, and as to amount of wages paid annually to workmen in Ontario per dollar profit earned, also as to time and risk involved in getting into a position to earn reasonable profits.

If these facts are carefully considered, we believe it will be found that but few companies in the Province have shown more enterprise or greater courage in the development of an industry, and that but few will be found to be of greater benefit to the Province in the amount of money spent in the Province for supplies and labor, in relation to profits earned. The company will require many years of operation yet before capital spent will be recovered, so that it may be questioned whether any "real profits" have been earned up to date.

When all the above facts are taken into consideration, we think it must be admitted that the company has borne, and is bearing, a just proportion of the total tax burden.

INCREASED TAXATION AS AFFECTING THE MOND NICKEL COMPANY, LIMITED

(MEMORANDUM NO. VII. FROM THE MOND NICKEL COMPANY, DATED 1915)

We beg leave to submit for the consideration of the Commission, the following discussion of an aspect of this matter of vital importance to the Mond Nickel Company.

The European war, which is taxing to the utmost the strength of the British Empire, has already caused in Great Britain an enormous rise in taxes, which may in fact be still further increased. The vast legacy of debt which must follow the war, will make such taxation a permanent burden.

From an Imperial point of view, this tax as affecting the Mond Nickel Company may, at least in large part, be considered as a contribution from this Province towards Imperial defence. It nevertheless must be paid out of profits by the Mond Nickel Company, who on this account are placed on an uneven footing relatively to other mining concerns in the Province, whose refinery and head office are not in Great Britain. The position of an all-British company undertaking its heavy share of the enormous tax burden due to the war, is greatly different from that of a company making huge profits by selling to Great Britain, perhaps indirectly in the form of munitions, at high prices, the nickel, which, while found within the Empire, is made to produce large profits to a neutral country, at Britain's expense and subject to no Imperial tax

The importance in the present crisis, of having the Mond Nickel Company's plant located in Great Britain, can hardly be overestimated. Instantly on the outbreak of war, the entire output of their nickel plant was placed at the disposal of the War Office and Admiralty. Even had the attempted submarine blockade been much more effective than it proved to be, stocks of matte and of nickel in process would have proven to be of great importance in tiding over the crisis.

The present war has shown the advantage, if not even the necessity of refining at least a considerable portion of the world's production of nickel not only within the British Empire but within Great Britain itself.

This being the case, does it seem just that a company refining in Great Britain and therefore contributing heavily in taxation to the British Treasury, should receive no different consideration in the matter of taxation within this Province, from a company operating its refinery in a neutral country and making large profits out of Great Britain's necessity, while contributing nothing to the British Treasury?

[*Mond Nickel Company*]

Evidence of Mr. C. V. Corless, Manager, Mond Nickel Company, Coniston

(Toronto, 13th October, 1916)

MR. GIBSON: Adverting to the matter of taxation, Mr. Corless, dealt with in your Memorandum No. V., you begin with the proposition that other things being equal taxation should be proportionate to the benefits derived by the person taxed? A. I make that statement as one of the principles of taxation.

Benefits Derived: Ability to Pay

Q. That is practically the only one that you deal with in the memorandum; but you would not confine taxation to that basis alone? A. Oh, no. I say that, other things being equal, that is the case. But other things are not always equal. I think every man who studies taxation will admit that that is one of the principles on which taxation is founded, but I have tried to make plain that it is not the only principle.

Q. Of course, the ability to pay is also regarded as a very considerable factor in any scheme of taxation? A. Absolutely, yes.

Q. If we were to confine our attention to the benefits derived alone, we would not get very far; but undoubtedly that is a factor. I notice you speak of local taxation for schools and municipal purposes in illustration of the principle that taxation should bear relation to the benefits derived. Well, is that really applicable to school purposes? A. I think it is, in a broad way, in the sense that a school section willing to pay a higher school tax is proportionately benefited by obtaining a better school. The principle is recognized in that, but it cannot be pushed to the limit.

Q. The persons who derive the greatest amount of benefit from the education are the children who are being educated? A. Yes.

Q. And in many cases, the parents of the children contribute little or nothing to the taxes? A. I know; but on the whole, if you look at the point as I have made it in comparing northern and southern Ontario, it is true, isn't it, that the municipality that is willing to pay liberally for education gets greater advantages than the one that is illiberal in the matter of education? Therefore the principle of paying for what you get does apply municipally, if it doesn't individually. Now, the point as I remember it, is in a connected argument leading up to a very great distinction in development between northern and southern Ontario.

Q. Yes, the main trend of your argument is to point out the disadvantages of northern Ontario in comparison with southern Ontario as regards transportation facilities, roads, telegraphs, etc? A. Yes, and particularly the fact that companies operating up there are already subject to what amounts to a tax, because they have to develop the country out of private capital before they can make use of their ore deposits

Q. Of course, that feature largely results from the fact that a mining industry is naturally situated in the poorer part of the country for agriculture? A Yes, we recognize that.

Q. Then, again, you speak of the fact that your company has had to pay large sums of money for mining properties to private owners? A. Yes.

Q. Middlemen, as it were? A. Yes.

Q. And you regard that money as being practically a royalty on your output? A. Yes, there is no other view we can take.

Q. Wouldn't it be fair to say that in purchasing any particular property offered to your company, you would take into consideration in fixing the price you could afford to pay, the fact that you would have to pay taxes on your profits? A. Well, of course, everything we have to pay, and all the ultimate profit we hope to get out, is figured in buying the property.

Q. This factor of taxation would naturally depress the price you would be willing to pay? A. Oh, yes, it certainly does, slightly.

Q. It is one of the things you consider? A. Well, of course, we consider all those things in getting the ultimate cost of our product; they are added in, and that naturally is added in with the rest.

Q. Would you go so far as to suggest that the government should levy a tax on sales of that kind? That is to say, if a mining company were to purchase a property for $500,000 should the government step in and say, "We will take a certain proportion of that price as a tax?" A. Well, I am quite willing to suggest the justice of that kind of tax; its practicability is a thing I have not thought out to a conclusion.

Q. One desirable feature about any particular taxation is simplicity? A. I cannot see why that could not be framed in such a way that it could be worked as easily as the present method. The government already has a Mine Assessor. I cannot see why a thing of that kind could not be added to his duties without any further charge to the government.

[*C. V. Corless.*]

Q. That might be so if all sales were made on a cash basis, but very often it isn't cash which is received as the purchase price, but stock in a company, which may be of problematical value? A. Even that could be allowed for. I think that could be worked out so as not to react unjustly.

Fair to Tax Increment Values

Q. It would be somewhat analogous to the British government tax on property sales now, except that they tax on the increment value and not on the total value? A. Well, this would be on the increment value. If a man has spent $75,000 on a property. I should say that should be deducted before the tax goes on. If he sells the property for half a million, deduct all legitimate expenses shown on his books, and then impose the tax. The reason it appears just to me is that these sums of money actually come as it were from the public domain. If the government wishes to get a similar sum of money from a company like ours and furnishes us with the ore, we would just as soon buy from it as from the individual.

Q. You mean if the Crown were the owner of the lands? But the Crown does not make the discovery of the ore, and that is the only thing that gives the land its value. Might not such a policy tend to discourage prospectors in looking for deposits? A. I think I have referred to that. That is a thing to be very carefully guarded against, for anything that would discourage prospecting, would be fatal to the industry. But I cannot see that, merely because a man finds a property which may be of almost fabulous value and gets a big price for it, it is just that he should get the entire sale price, when he perhaps only happened to stumble on to the discovery. It seems to me that a general distribution of a part of the price is only just. In other words, prospecting for a mine is of an entirely different nature from the exploration and development of it. In the latter case, the government is satisfied with a small continual tax on product. The prospector may "strike it rich" in the first few days, or he may have bad luck for years. All his expenses for prospecting should be allowed before application of the tax. It is a very difficult problem, but I cannot help feeling it unjust that the government appears at present to take no cognizance whatever of the fact. Let us say, for instance, a company like our own may pay a million dollars for a property. We get no recognition for this in taxation. The man who has received the million dollars, and who has done practically nothing for it, is not taxed on the increment. At the same time I don't wish it understood that I bear any malice toward the man we bought from or anything of that sort. We have recognized the conditions; we have bought properties because we wanted them, and if they could get two million for their property instead of one, I don't blame them.

Q. I presume the Mond Nickel Company thought they were getting value for their money? A. Exactly. At the same time I would have felt better if a good portion of the money our company has paid for mines had gone into the government purse instead of to private individuals, in cases where very little has been done by the individual. Put it in this way if you like: a company goes into the district in the early days and is able to get hold of large properties at a very small figure, and another one comes in at a later date and pays a very high price It seems to me the government ought to equalize those conditions. In the latter case, a portion of the revenue should come out of the company and a portion out of the person who gets the money. I think such a tax should be progressive, somewhat like a succession tax.

Q. Isn't the situation in some degree regulated by the present system of mine taxation which has relation to the profits the company makes? A. This whole argument has no reference whatever to the present system of taxation. The idea I had when I wrote that memorandum was that there was a general feeling that mining companies should be very heavily taxed, the present tax being a comparatively small matter. With regard to the present system of taxation, I have no criticism whatever. I think the present system properly applied is just.

Q. It is a just and equitable system of taxation? A. I think so. There may be some difficulty in the application of it, particularly in the case of ores like those in the Sudbury district, because of the settling the value of the ore at the pit's mouth; but I don't think the difficulty is insuperable.

Q. It has value, but the question is to ascertain that value? A. Yes.

CHAIRMAN: You speak in your memorandum here of the mines of South Africa, Australia and Tasmania. You probably know that in South Africa there is a tax of 10 per cent. on the profits of the gold mines? A I know there has been very heavy taxation levied recently or been talked of. I don't think the reference I made to South Africa is in connection with that so much as to the stability. So much agitation against the companies that are doing business is very unsettling.

[*C. V Corless.*]

MINNESOTA AND ONTARIO LAWS CONTRASTED

Following is a letter written to the Commission by Mr. Fred B. Snyder, of Messrs. Snyder and Gale, attorneys at law, Minneapolis, Minn., 13th January, 1917, comparing the Minnesota and Ontario mining tax laws, to the disadvantage of the former.

"In Minnesota, where minerals are taxed in the ground, hardship is sometimes done to the man least able to stand it. For example—a landowner in Minnesota gives an option to an explorer to search for ore. As a result of the exploration an orebody is found, but it may be of so low grade that it is not presently marketable, or at the time remote from transportation. The explorer, however, deems the orebody of sufficient value to take out a lease, which he does. Now under the Minnesota law he is required to file with the Tax Commission blueprints showing the extent of the orebody discovered by him. The Tax Commission from this information values the orebody, as well as the land as a farm, and spreads the assessment on the tax books against the land. As long as the lessee holds the lease he is required to pay the tax, but it is usual in ore leases (and as far as I know all Minnesota ore leases contain such a provision) to insert a provision in the lease permitting the lessee to surrender the lease for cancellation upon giving notice and paying all demands to the date of surrender. So it often happens that lessees for one reason or another surrender their leases before the property is opened or any betterments placed thereon. The result is that the land comes back to the owner with the imposition thereon of an annual tax far in excess of his ability to earn or to pay.

"Such a law also tends to discourage prospecting and exploration work. In a new country every opportunity should be held out by the government to induce settlers and explorers to develop the natural resources. The tax law which is now in force in your country, providing for a tax on the profits derived from the operating of open mines, tends to the development of your natural resources and should, I think, be retained and have the cordial endorsement of your Commission."

MEMORANDUM *RE* TAX PAID BY THE CANADIAN COPPER COMPANY

By G. R. Mickle, M.E., Mine Assessor

As there has been persistent discussion in the press about this matter, it seems advisable to make it plain that the objections raised to the amount of the tax paid last year (1915) are based on a complete misunderstanding of the Act under which the tax is levied. In some of the articles it is alleged the tax should have been something like $400,000 instead of $40,000, and the way the larger sum is arrived at is given with an appearance of desire for accuracy lent by quoting word for word the section in the Mining Tax Act (sec 5) which states that every mine shall pay a tax of three per cent. on the annual profits in excess of $10,000.

Provisions of Mining Tax Act

It is difficult to believe that anyone taking the trouble to quote this exactly, should not have continued reading this same section, and found out what the annual profits mean and how they are to be calculated. Anyone doing this would see that it is only when all the product of the mine is sold direct that a company is liable for three per cent. of its annual profits as a tax. If, however, the product is not sold but is treated, then a value must be put on it at the pit's mouth by the Mine Assessor, when there is no established market value, as is the case here. All this is fully explained in section 5.

In arriving at the tax of $400,000 approximately, a valuation of $17,000,000 is put on the product at the pit's mouth. As the tax for 1915 is based on operations of 1914 when 618,781 tons were smelted by the Canadian Copper Company, it can be seen that this means a valuation of over $27 per ton for the ore at the pit's mouth, which will be shown presently to be perfectly absurd, as there is no record up to the present of any nickel ore of similar grade anywhere having been sold at anything like this figure.

The opinion is expressed or inferred that something unusual and improper was done in making a temporary arrangement for a fixed amount per year. There is this essential difference between the taxation of this company and any other company in Ontario producing minerals other than nickel and liable for a tax, in that, in all other cases, either the product of the mine is sold direct or subjected to a treatment incomparably simpler than the nickel ore undergoes, and for which either customs works have established rates, or in some cases there is an established market price for the product of the mine, so that a very close approximation of the amount of tax which should be levied under the Act can be made. But in the case of a company mining, smelting and refining its own nickel ore, no such close approximation is possible. It involves an arbitrary determination of one value. As the tax is a fixed proportion of the difference between two things, viz., the valuation of the ore, and the expenses which may be deducted, and these expenses can be definitely ascertained

beyond dispute, it is plain that fixing an arbitrary value of the ore as the Act requires shall be done, thereby automatically determines an arbitrary amount for the tax. Moreover, the Act does not place any limitation on the method to be followed in appraising the value of the ore at the pit's mouth. There can be no objection, therefore, to the legality of this action.

Value of New Caledonia Ore No Guide

At the time the arrangement regarding taxes was made, viz., about the end of 1913, there was no information available to determine a market value for the kind of ore in question. As a matter of fact at that time this particular class of ore had never been bought and sold in such a way that a market price could be said to exist, that is, there had not been a number of transactions made openly under competition. It is true nickel ore of an essentially different kind (not being combined with copper) had been sold for years in New Caledonia, and market rates for that kind of ore established there. If the same value had been assigned to the Sudbury ores as have been estimated for New Caledonia, it is doubtful if any taxes would have been paid at all. Thus the quotations given for 1912, which were the latest at the time the arrangement was made, showed that for ore containing 6.05 to 6.49 per cent. nickel (when dry) the value was 0.65 francs per kg., equivalent in our system to 5.70 cents per lb. nickel metal. A 7.0 per cent. ore was worth .80f. per kg, or 7.0 cents per lb That is, although the mean of these first, *viz.*, 6.27 per cent. ore is just 90 per cent. as rich in nickel, the value is only 80 per cent. as much per lb. of metal as in the 7 per cent. ore. If we assume for a moment that this rate of decrease in value per lb. of metal is directly proportional to the drop in the percentage, we have a difference of .73 per cent, causing a drop in value per lb. of metal of 1.3 cents, and the interval between 6.27 per cent. and the best of the Sudbury ores or 3.9 per cent. nickel is 2.37 per cent., which is 3.2 times as great as .73, therefore this should cause a difference of 4.16 cents per lb. Deducting this from 5 7 cents leaves only 1.5 cents per lb. for nickel. Accordingly a 4 per cent. ore with 80 lbs. nickel per ton would be worth only $1 20 as far as the nickel is concerned. To this must be added the value for copper, which would be less than above amount.

It can be shown, however, that this is too favorable a calculation, and that according to these quotations an ore containing 4.31 per cent. nickel is worth exactly nothing. Proof of this is given separately. This coincides with the fact that no quotations are ever given for New Caledonia ores as low in nickel as the Sudbury ores, and therefore we have no right to assume they would have any market value in New Caledonia. Moreover, the quotations for later years, 1915 for instance, are somewhat lower than given above. It is plain then that the only well established market quotations for nickel ores are of very little help in attempting to ascertain the value of the Sudbury ores, and that their worth must be determined by the conditions existing in that locality. At the time the arrangement regarding taxes was made with the Canadian Copper Company, a small amount of ore had been sold by the Alexo mine in the Temiskaming district on a certain tariff or schedule. The fact that the price paid was not made public and the transactions were limited, seemed to prevent this being regarded as establishing a market price. Moreover, if this rate had been accepted as a valuation for tax purposes, it would have meant that some of the ore mined now, and a great deal of the lower grade ore that will be mined in the future, would escape taxation altogether.

How Amount of Tax Arrived At

It is obvious that any valuation is purely arbitrary, and could not even be considered as a very close approximation. Many calculations were made with the object of establishing a mode of valuation. They could all be met with serious objections. It seemed easier to arrive at an equitable tax under the Act by assigning an arbitrary proportion of the total profits made in the whole treatment from ore to refined metal, to the various operations involved, viz., (1) mining (including possession of the ore), (2) smelting and converting, (3) refining and marketing. It is clear that all profit must be divided among these three operations

Taking, first of all, smelting and converting, and comparing this with refining and marketing, these operations being somewhat similar in nature, and therefore more easily compared, it does not seem that the smelting and converting is entitled to nearly as great a share of the total profits as refining and marketing, since in spite of the expensive plant required the former operation follows the practice developed in the treatment of copper ores and mattes, whereas a method had to be invented to separate and refine the copper and nickel. It may be stated that the marketing of even a long established metal like copper, accounts for a not inconsiderable part of its total value as refined metal. This becomes more important in the case of a metal like nickel, the use of which had to be continually pressed in an educative campaign. It would seem then that the refining and selling is entitled to a much greater share of the total profits than the smelting and converting, probably twice as much. Represent the share assigned to refining at 2, and smelting at 1. Comparing now the mining (including possession of the ore) with refining, it is clear in the first place that it owes its value almost entirely to the fact that

workable bodies of ore of this nature are extremely rare. If bodies of ore equal or greater in richness and extent were found in any accessible part of the world, this fact would profoundly affect the value of these ores. It is therefore rather the possession of the ore than the act of mining which would govern the value.

Comparing this mining with refining and marketing, it is difficult to see how a difference could be made between them with regard to their respective claims to a share of the whole profits. It is plain that the ability to refine and market a nickel-bearing product is of no value without the ore as the source of the nickel. On the other hand, the experience of the past has shown that the possession of the ore and the ability to smelt it is of no value unless the resulting product can be refined and marketed. No less than four companies have mined and smelted nickel ore in the Sudbury district, and then abandoned the enterprise. They all had ore, they were all able to smelt, and yet the venture failed. Only one company outside the Canadian Copper Company has up to the present succeeded in disposing of its mined and smelted nickel product. This was due to its possession of an ingenious and elaborate method of refining. As it seems impossible to establish a difference between the claims of the refining and marketing, and those of the mining, for a share of the total profits, they must be considered as entitled to the same proportion of the whole, that is, 2 would represent the profit of mining, 1 the profit of smelting, and 2 the profit of refining, or in percentages, 40, 20 and 40, respectively.

Five Millions Profit per Annum

Returning to the arrangement arrived at, it is based on the operations of 1911-1915 inclusive, and when made, two of these years, 1911 and 1912, were past; it was also known that 1913 did not differ much from 1912. There was merely a gradually increasing production. The profits made by the International Nickel Company for the calendar years 1911-1915 will be approximately the same as for the fiscal years of the company ending 31st March, 1912-1916, save that we know there was a serious curtailment of operations at the outbreak of the war in 1914, in consequence of which the actual tonnage smelted in 1914 was smaller than in 1913, as will appear in table below. It was not until March of 1915 that the old rate of monthly production was again reached. Since that time the output has been accelerated. The profits for the fiscal years most nearly corresponding to the calendar years 1911-1915 are as follows, quoted from the company's reports:

Year ending 31st March, 1912	$3,581,959 67
Year ending 31st March, 1913	5,020,304 92
Year ending 31st March, 1914	4,792,664 75
Year ending 31st March, 1915	5,598,071 21
Year ending 31st March, 1916	11,748,278 53

The tonnage smelted for the calendar years in question was as follows:

	Tons ore.
Calendar year 1911	462,109
Calendar year 1912	594,209
Calendar year 1913	665,751
Calendar year 1914	618,781
Calendar year 1915	865,168
Total	3,206,018

or an average of 641,203 tons for the first five year period. It will be noted that up to 1914 the fiscal year will agree fairly closely with the preceding calendar year in the profits; but for the fiscal years ending in March, 1915 and 1916, the calendar year will show a smaller profit, for the reason explained above Thus for the calendar year 1915 the tonnage smelted was 865,168, whereas for the fiscal year ending March, 1916, it was 1,000,919 tons. The profit proportional to the tonnage would be $10,154,000, approximately instead of eleven and three-quarter millions. It will be seen that a profit of five million dollars per year was a reasonable estimate for the five-year period 1911-1915 according to calendar years, or 1912-1916 as reckoned by the company's fiscal year. Assigning 40 per cent. of this to mining, gives a profit of two millions, three per cent. on which is sixty thousand dollars. Every mining company, however, has the right under section 14 of the Mining Tax Act to deduct municipal tax paid on income up to one-third of the whole tax. The Canadian Copper Company was obtaining a large part of their output from a township with no municipal organization, and consequently there were no taxes levied, although the company were constructing and maintaining roads, schools and a hospital as a municipality would have done, and its annual expenditure for these purposes was considerably greater than one-third of the Provincial tax calculated above. For example, it is considered that the hospital at Copper Cliff, built and maintained by the com-

[*G. R. Mickle*]

pany, is superior to anything in Ontario outside of Toronto. In agreeing to pay a tax of $40,000, the company waived its statutory right to organize the township, as could be easily done, and then deduct one-third of the tax.

From the above statement, it will be seen that the tax paid in 1912 was somewhat too high. For 1913, 1914 and 1915 (considering that the calendar year 1914 was not as favourable as the fiscal year ending March, 1915), it was a very close approximation. The same amount for the year 1916 is too small, due solely to the extraordinary demand for nickel, and the abnormally high price of copper caused by the war. Nothing like this has ever occurred in the history of the metal industry before. On the other hand, only a few years back, in 1907, the Canadian Copper Company was in a serious condition due to industrial depression and in 1893-94 the works were entirely closed for about a year, so that judging from past experience if anything abnormal happened to nickel mining, the chances were in favour of the government under the fixed taxation. If there had been no disturbance of normal conditions, the tax for 1916 would have been as near an approximation as could be had.

Proof that New Caledonia Ore of 4.31 Per Cent. is Worth Nothing

It is evident there must be some grade of ore which is worth exactly nothing. Treating ore below this grade would cause a loss, and above this a profit. This percentage where the ore is worth exactly nothing may be called the "neutral point." Let us assume for a moment that 2 per cent. or 40 lbs. metal per ton is the neutral point. Now all ore with a percentage of metal above this must have some value. Assume that a 3 per cent. ore or 60 lbs. per ton is worth $2.00 per ton. Then increased percentages above this neutral point will have values increased proportionately above the neutral point. Thus a 4 per cent. ore (80 lbs. per ton) will be worth just twice as much as 3 per cent. ore, because it has 40 lbs. per ton above the neutral point, as against 20 lbs. per ton for the 3 per cent. ore, since it is only the metal in excess of the neutral point which can be regarded as having any value, and the whole value in the ore must be considered as distributed equally over each unit of metal above the neutral point.

The problem is to find the neutral point, knowing the variations in price per lb. of metal paid for two different grades of ore. In the case in question the 3 per cent. ore, with 60 lbs. per ton worth $2.00, would give a quotation of 3.3 cents per lb. and the 4 per cent ore would be quoted at 5 cents per lb. Now let x = number of lbs. metal per ton in neutral ore. Then in case of 3 per cent. ore, 60 — x equals lbs. per ton in excess over neutral point on which the value is to be distributed and 60 — x = 200c. by hypothesis. Therefore value per lb. metal in this excess is $\frac{200}{60-x}$ And similarly with the 4 per cent. ore, which is worth $4.00, 80 — x equals metal in excess of neutral point and, as before, $\frac{400}{80-x}$ is value per lb. metal in this excess. But the value of each lb. of metal above the neutral point is the same (within certain limits) therefore

$$\frac{200}{60-x} = \frac{400}{80-x}$$
$$16000 - 200\,x = 24000 - 400\,x$$
$$200\,x = 8000$$
$$x = 40 \text{ lbs. per ton or 2 per cent.}$$

Now in a similar way, a 6.27 per cent. ore or 125.4 lbs. at 5.7 cents = $7.14.
and 7.00 per cent. ore or 140 lbs. at 7 cents = $9.80.

$$\text{and } \frac{714}{125\,4-x} \quad \frac{980}{140-x}$$
$$714\,(140-x) = 980\,(125.4-x)$$
$$99960 - 714\,x = 122892 - 980\,x$$
$$266\,x = 22932$$
$$x = 86.2 \text{ lbs. per ton.}$$
$$= 4.31 \text{ per cent.}$$

Toronto, 20th November, 1916.

FURTHER MEMO RE VALUATION OF NICKEL COPPER ORES

By Mr. G. R. Mickle

Supplementing the memo regarding tax paid by the Canadian Copper Company dated 20th November last it seems advisable to prove by further independent reasoning that the valuation of over $27.00 per ton at the pit's mouth which must be made by those claiming that the tax should have been $400,000 or more, is entirely unwarranted, and that any evidence that exists as to the market value of nickel-bearing ore of this kind, shows that the value is about one quarter of this amount.

As the output of the mines belonging to the Canadian Copper Company was not sold but was treated, it became necessary, under the Mining Tax Act, there being no established market price, to appraise the value of the product at the pit's mouth. It seems perfectly clear that it is the intention of the Act to determine as nearly as possible, what the market value would be, if there were one; in other words, the probable market value. This is plain from the following consideration:—The product of the mine in order to be taxable must be either sold or treated. If sold, the sale must be at the market price, if there is one. It is, moreover, difficult to see how there could be a number of transactions in any commodity extending over any considerable period without establishing a market price. Hence, sooner or later, any sale must be at the market price. Furthermore, in the case of the ore that is not sold but treated, the Act explicitly states that the established market value at the pit's mouth shall be ascertained, and from this the deductions specified in the Act made in order to find the taxable value. It is only in the absence of all these conditions which clearly put the market price as the governing factor in determining the taxation, that it becomes necessary to make an appraisal of the value. It seems therefore plain that this same principle must be followed, and that every effort must be made to ascertain the probable market value.

As stated in the memorandum above referred to, the only place where nickel ores had been sold in such a way as to establish a market price was in New Caledonia, and the prices were on a sliding scale of so much per pound metal contained in the ore according to the richness. Thus for a 6.27 per cent. (dried) ore, the price was 5.7 cents per lb. nickel and for a 7 per cent ore (dried) it was 7.0 cents per lb. nickel. A great part of this was sold to buyers in various countries in Europe, and the yearly amount thus sold was 100,000 tons or more. This trade has been going on for ten years or more, so that a million tons or so have been sold, and market rates established in Europe. Although this ore is essentially different from the Sudbury ores, and therefore need not necessarily have the same market value, still it is the only nickel-bearing ore for which a market price has been established, and therefore it cannot be ignored.

This ore contains about 20 per cent. moisture on the average, but as the ore must be dried before being analysed, and the moisture in any event varies according to the weather, the quotations are always on the dried ore. Now an ore with 6.27 per cent. nickel when dried will contain just 5 0 per cent. nickel in the wet state; this is 100 lbs nickel to the ton, which at 5.7 cents per lb. gives $5.70 per ton. The freight to Europe fluctuates of course, but before the war about $7 00 per long ton may be taken as the average, this would be equal to about $6.30 per ton of 2,000 lbs., making a total of $12.00 per ton for this ore in Europe. In the same way a 7 per cent. ore (when dried) which contained before drying 20 per cent. moisture, would have 5.6 per cent. nickel in the wet ore, equal to 112 lbs. per ton, this at 7 cents given $7.84, adding $6.30 for freight gives $14.14, as market price for this kind of ore in Europe.

The explanation of the "neutral point" was fully discussed in former memorandum, and the way the "neutral point" can be calculated was explained.

Neutral Point in New Caledonia and Sudbury Ores

In exactly the same way the neutral point, or the percentage in this wet ore in Europe which is worth exactly nothing, can be found from the information given above. Thus x being the number of pounds per ton in ore at the "neutral point" we have the equation:—

$$\frac{1200}{100 - x} = \frac{1414}{112 - x}$$

which gives finally $x = 32.7$ lbs. per ton.
$= 1.63$ per cent. nickel.

Compare this neutral point of 1.63 per cent in ore with 20 per cent. moisture, with dry ores as in Sudbury. The moisture is easily expelled by heat, and therefore the neutral point becomes 2.03 per cent. in the dried ore. This ore has a market value in Europe of $12.00 per ton, and it has an excess over the neutral point of the difference between 6.27 and 2.03 or

[*G. R. Mickle.*]

4.24 per cent., and as proved before the values (within certain limits) of two ores of different grades are directly proportional to the amount of metal in excess of the neutral point. The Sudbury ore with 3.9 per cent. nickel or 1.87 per cent. excess will then be worth as follows:—

$$\frac{\$12.00 \times 1.87}{4.24} = \$5.29$$

for nickel content. To this must be added price for copper, as the ore contains about 1.7 per cent. copper. With the usual deductions made for losses in buying copper ores, this could hardly be considered worth more than $1.70 per ton. considering the difficulties of the separation from the nickel, making in all $7.00 per ton as the calculated market value of an ore similar to the Sudbury ores in Europe. This is just a little more than one-quarter of the value assigned to the ore by those appraising it at over $27.00 per ton at the pit's mouth.

A further indication of the probable market value of these ores may be obtained from the sale of ore by the Alexo mine in the Temiskaming district. Several hundred thousand dollars' worth of ore have been bought and sold at a price based on the nickel and copper content. For an ore averaging over a considerable period 4.34 per cent. nickel and 0.58 per cent. copper, the price paid comes to $6.64 per ton, or again less than one-quarter of the pit's mouth value assigned to the Sudbury ore by those who claim that the tax should have been $400,000 or more. Moreover, to obtain the taxable value of the ore all the expenses of getting it to the surface, transportation, etc., specified in the Act must be deducted—scarcely noticeable if the value is over $27.00 per ton, but making serious inroads on $6.64. There is no question in the case of the Alexo ore, where we have a direct sale of ore, that the proper value according to the Act, which is merely the receipts from sales, has been given. It is correct and indisputable to the last cent, and it would seem absurd that by any method of reasoning another ore which must have very nearly the same value should be appraised for the purposes of taxation under the very same section in the same Act at more than four times as much.

Furthermore if the probable market value—which is clearly the thing intended by the Act—of these ores in question were over $27 00 per ton or anything approaching that, it is inconceivable that deposits of nickel-bearing ore, as for example the Murray mine, would lie idle for twenty years or more.

Toronto, 18th December, 1916.

SECTION O

WATER POWER DEVELOPMENT IN NORWAY[1]

Available Power

The total amount of water power in Norway which may be easily developed is now estimated to be about five million K.W.[2] There is no doubt, however, that the real figure is considerably greater, as the power available in many cases, especially where the waterfall is situated at some height above the level of the sea, has shown itself to be considerably in excess of the estimated output.

Of the 5,000,000 K.W. mentioned above, about 700,000 K.W. is now used for the generation of electric power. The distribution of this power for various purposes is approximately as follows:

		Per Cent.
For lighting purposes, approximately	85,000 K.W.	12
For power, approximately	230,000 K.W.	33
For electrochemical purposes, approximately	300,000 K.W.	43

The remaining 12 per cent. is used for a variety of purposes, and also includes excess of generator capacity, reserve, etc.

There are also some waterfalls which are not used for generation of electric power, but for direct drive, particularly for wood pulp mills, etc. The total amount of power from these waterfalls is small, however, as compared with the amount mentioned above.

Of the remaining 4¼ million K.W. the Norwegian government owns about ¾ million K.W., the rest being for the greatest part in private possession.

These waterfalls have been bought by the government, mainly with the object of providing power for the electrification of the railways, which are almost, without exception, owned by the government, but also with the idea that the government may some time have to transmit electric power in bulk to those parts of the country where no suitable water power is available within a reasonable distance. Up until now none of the waterfalls belonging to the government have been developed, but work is now being begun on these as well.

The distribution of electricity for domestic and small industrial purposes is mostly carried out by the municipalities. Lately, the municipalities have also begun to acquire water power on a more considerable scale in order to supply power for larger industries as well. The total amount of water power now owned by the municipalities, including that which has already been developed, is about 600,000 K.W.

The waterfalls in Norway are fairly well distributed all over the country, but the majority of them are along the west coast, and in most cases are so situated that the power station may be built right at the sea level. The same holds good for many waterfalls in the northern part of the country. In most of these cases access is easy, and a good harbour, open all the year round, is to be found in the immediate vicinity. In some places some difficulty may be experienced in finding suitable ground for factory buildings, etc

The cost of developing water power naturally varies considerably, but as there is generally a high available head and a comparatively small flow, the costs are as a rule low.

The total costs, including purchase of the necessary rights and ground, also electrical generators in the power station, but not transformers for high tension transmission, may be taken to vary between Kr.[3] 250 and Kr. 400 per K.W for plants from 10,000 K.W. and upwards.

The annual costs, including depreciation, may be taken as from 10 per cent. to 15 per cent. of the initial outlay. A cost of Kr. 45 to 60 per K.W. per year may apparently be taken as a fair average figure for power delivered at a seaport in blocks of not less than 5,000 to 10,000 K.W. and at a pressure between 5,000 and 15,000 volts.

The cost of power will generally be less in the western and northern part of the country than in the eastern and southern part, owing to the fact that the waterfalls in these parts are generally more conveniently situated and also more cheaply developed.

Legal Regulations

The water power in Norway always belongs to the owner of the land adjacent to the river. The rights may be sold independently.

When developing water power, existing fishing rights, transportation of timber by floating, etc., also have to be taken into account.

[1] By Karl von Krogh, New York.
[2] Kilowatt = 1 34 horse power.
[3] Kroner = $0.268.

[*K. von Krogh.*]

The owner of a waterfall may obtain permission from the government to expropriate land, etc., necessary for the building of dams, and erecting pipe lines and also the land necessary for the regulation reservoirs. He cannot, however, expropriate parts of the water power which, for instance, might be necessary in order to economically develop a waterfall as a whole.

Regarding these matters, see "Lov om Vasdragenes benyttelse" (Law regarding the Use of Waterways, etc.) of July 1st, 1893, with Amendments of July 14th, 1893; July 19th, 1907, and August 18th, 1911. Also "Law regarding the Regulating of Water Power for Industrial Purposes" of August 4th, 1911, with Amendment of February 20th, 1913.

Water power may be expropriated by a municipality, but only to provide electric power for the purpose of lighting and for small industries. This question is regulated by "Law regarding compulsory cession of Waterfalls to Municipalities" of August 15th, 1911, amended by Law of July 12th, 1912.

An institution peculiar to Norway is the so-called right of "Odel," which permits the land owner or one of his descendants within a certain period (3 years) to buy the land back by compulsion if he so wishes. In case the price cannot be agreed upon, it is fixed by a taxation jury, and the rule is that the value of the land to the purchaser (not the original owner) shall be the basis for fixing the price. All improvements, buildings, etc, must be paid for.

Lately, this right has been modified in such a way that industrial improvements, such as power stations, factories, etc., are exempted from compulsory redemption, and also the land necessary for such improvements.

The Position of Foreigners

The acquisition of water power, by subjects of a foreign state, limited companies, etc., are subject to permission from the government Such permission is also necessary to buy electric power, produced from water power

To these permissions are generally attached certain conditions intended to protect national interests, and to further national industry

One of the conditions, as a rule, is that a certain percentage of the water developed (generally up to 10 per cent.) must be rented to the municipality or to the State government (if required by them) at a certain fixed price.

This question is regulated by the "Law regarding the Acquisition of Waterfalls, Mines and Other Properties" of September 18th, 1909.

The erection of electric power stations and of any electrical plant must be carried out according to government regulations. For low tension plants (below 500 volts D.C. and 250 volts A.C.) fixed rules are issued; for the erection of high tension plants permission must be sought for each case, and the regulations are issued along with the permission.

The permission to erect high tension plants may now also, according to temporary law, be made subject to other conditions which the government should find to be in the interest of the community as a whole.

The ground, or right of way, necessary for the erection of transmission lines, may be expropriated with the permission of the government, provided that other public interests are not considered to suffer from such erection.

These questions are regulated by "Law regarding Measures to Safeguard against Danger and Inconveniences caused by Electric Plants," etc., of May 16th, 1896, with amendment of July 19th, 1912, and "Law regarding Compulsory Cessation of Ground, etc., for the Erection of Electric Transmission Lines," of July 23rd, 1894 Also by provisional Law of July 26th, 1916, amending the two Laws mentioned above.

[*K. von Krogh.*]

SECTION P

TABLES, FACTORS AND CALCULATIONS

(1) INTERNATIONAL ATOMIC WEIGHTS FOR 1917

(The asterisks indicate where changes have been made by the International Committee on Atomic Weights since 1911.)

Element	Symbol	0=16.
Aluminium	Al	27.1
Antimony	Sb	120.2
Argon	A	39.88
Arsenic	As	74.96
Barium	Ba	137.37
Bismuth	Bi	208.0
Boron	B	11.0
Bromine	Br	79.92
Cadmium	Cd	112.40
Cæsium	Cs	132.81
Calcium*	Ca	40.07
Carbon*	C	12 005
Cerium	Ce	140 25
Chlorine	Cl	35.46
Chromium	Cr	52.0
Cobalt	Co	58.97
Columbium*	Cb	93.1
Copper	Cu	63.57
Dysprosium	Dy	162 5
Erbium*	Er	167.7
Europium	Eu	152.0
Fluorine	F	19.0
Gadolinium	Gd	157.3
Gallium	Ga	69.9
Germanium	Ge	72 5
Glucinum	Gl	9.1
Gold	Au	197.2
Helium*	He	4 00
Hydrogen	H	1.008
Indium	In	114.8
Iodine	I	126.92
Iridium	Ir	193.1
Iron*	Fe	55 84
Krypton	Kr	82.92
Lanthanum	La	139.0
Lead*	Pb	207 20
Lithium	Li	6 94
Lutecium*	Lu	175.0
Magnesium	Mg	24.32
Manganese	Mn	54.93
Mercury*	Hg	200.6
Molybdenum	Mo	96.0
Neodymium	Nd	144.3
Neon	Ne	20.2
Nickel	Ni	58.68
Niobium, *see* Columbium.		
Niton* (radium emanation)	Nt	222.4
Nitrogen	N	14.01
Osmium	Os	190.9
Oxygen	O	16.0
Palladium	Pd	106.7
Phosphorus	P	31.04
Platinum	Pt	195.2
Potassium	K	39.10
Praseodymium*	Pr	140.9
Radium*	Ra	226.0
Rhodium	Rh	102.9
Rubidium	Rb	85.45
Ruthenium	Ru	101.7
Samarium	Sa	150.4
Scandium	Sc	44.1
Selenium	Se	79.2
Silicon	Si	28.3
Silver	Ag	107.88
Sodium	Na	23.00
Strontium	Sr	87.63
Sulphur*	S	32.06
Tantalum*	Ta	181.5
Tellurium	Te	127.5
Terbium	Tb	159.2
Thallium	Tl	204.0
Thorium	Th	232.4
Thulium	Tm	168.5
Tin*	Sn	118.7
Titanium	Ti	48.1
Tungsten	W	184.0
Uranium*	U	238.2
Vanadium*	V	51 0
Xenon	Xe	130.2
Ytterbium (Neoytterbium)*	Yb	173.5
Yttrium*	Yt	88.7
Zinc	Zn	65 37
Zirconium	Zr	90.6

(2) FACTORS CONNECTED WITH THE SMELTING AND REFINING OF NICKEL AND COBALT

	Ni. per cent.
NiO	78.58
NiH_2O_2	63.31
$NiCO_3$	49.48
NiS	64.66
$NiSO_4.7H_2O$	20.89
$(NH_4)_2Ni(SO_4)_26H_2O$	14.87
$K_2Ni(SO_4)_26H_2O$	13.44
$NiSO_4$	37.92
$NiCl_2$	45.28
$Ni(NO_3)_2.6H_2O$	20.18
$Ni(CO)_4$	34.38

	Co. per cent.
CoO	78.66
CoH_2O_2	63.44
$CoSO_4$	38.04
$CoSO_4.7H_2O$	20 97
$CoCl_2$	45.38
$Co(NO_3)_25H_2O$	20 25

	Cu. per cent.
CuO	79.89
CuH_2O_2	65.13
$CuSO_4$	39.81
$CuSO_4.5H_20$	25.46
$Cu(NO_3)_2.6H_2O$	21.49
$Cu(NO_3)_2 3H_2O$	26.29
$CuCl_2$	47 21

	Fe. per cent.
FeO	77.73
Fe_2O_3	69.94
Fe_3O_4	72.36
FeS_2	46.54
FeS	63.52
$FeSO_4.7H_2O$	20.09

	S. per cent.
SO_2	50.06
SO_3	40.05
H_2SO_4	32.70
FeS_2	53.46
FeS	36.48
H_2S	94.09

		Per cent.
As_2O_3	contains	75.75 As.
$CaCO_3$	"	43 97 CO_2
$CaCO_3$	"	56.03 CaO.
CO_2	"	27.27 C.
CO	"	42.86 C.
NaCl	"	60.66 Cl.
H_2O	"	11.19 H.
H_2O	"	88 81 O.

(3) MELTING POINTS

Element.	°C.	°F.
Tin	231.9	449.4
Cadmium	320.9	609.6
Lead	327.4	621.3
Zinc	419.4	786.9
Antimony	630.0	1166
Magnesium	651	1204
Aluminium	658.7	1217.7
Silver	960.5	1761
Copper	1083.0	1981.5
Gold	1063.0	1945.5
Manganese	1260	2300
Grey cast iron	1100	2012
Silicon	1420	2588

Element	°C.	°F.
NICKEL	1452	2646
COBALT	1480	2696
Chromium	1520	2768
Iron	1530	2786
Palladium	1549	2820
Platinum	1755	3191
Molybdenum	2500	4500
Tantalum	2850	5160
Tungsten	3000	5430
Steel	1400	2552
Wrought iron	1600	2912
Monel metal	1360	2480

(4) DESULPHATIZATION OF ANHYDROUS SULPHATES BY HEAT

(General Metallurgy, Hofman, 1913.)

Composition.	Temperature at which decomposition commences.	Temperature of energetic decomposition.	PRODUCTS.	
			Composition.	Color.
	Degrees C.	Degrees C.		
$FeSO_4$	167	480	$Fe_2O_3(SO_3)_2$	Yellow-brown.
$Fe_2O_3(SO_3)_2$	492	560	Fe_2O_3	Red.
$CuSO_4$	653	670	$2CuO.SO_3$	Orange-color.
$2CuO.SO_3$	702	736	CuO	Black.
$MnSO_4$	699	...	Mn_3O_4	Dark red to black.
$NiSO_4$	702	764	NiO	Brownish-green.
$CoSO_4$	720	770	CoO	Brown to black.
$ZnSO_4$	702	720	$3ZnO(SO_3)_2$	White, cold and hot.
$3ZnO(SO_3)_2$	755	767	ZnO	Hot,—yellow; cold —white.
$CdSO_4$	827	846	$5CdO(SO_3)$	White.
$5CdO\ SO_2$	878	890	CdO	Black.
Ag_2SO_4	917	925	Ag	Silver white.
$PbSO_4$	637	705	$6PbO\ 5(SO_3)$	White
$6PbO.5SO_3$	952	962	$2PbO\ SO_3(?)$	White to yellow.
$Bi_2O_3(SO_3)_3$	570	639	$5Bi_2O_3.4(SO_3)_3$	White.
$5Bi_2O_3.4(SO_3)_3$	870	890	$Bi_2O_3(?)$	Yellow.
$Al_2O_3(SO_3)_3$	590	639	Al_2O_3	White.
$MgSO_4$	890	972	MgO	White.
$CaSO_4$	1,200	...	CaO	White.
$BaSO_4$	1,510	...	BaO	White.

Kern and Walter (Sch. of Mines Quarterly, 1911, V. 32) give decomposition temperatures as: $FeSO_4$ 580°, $CuSO_4$ 647°, and $NiSO_4$ 727°. They state that, above 280°, a basic iron sulphate, $Fe_2(SO_4)_3FeO$, is produced, that above 727°, a basic nickel sulphate is formed and that no basic sulphate of copper is produced on heating the ordinary sulphate.

(5) SOLUBILITIES AND STRENGTH OF SOLUTIONS

The following tables in connection with solubilities and strengths of solutions are quoted from Comey's "Solubilities," 1896, and Seidell's "Solubilities," 1907.

Sp. gr. of $NiSO_4$ + Aq at 0°. S = pts. $NiSO_4$ in 100 pts. solution; S_1 = mols. $NiSO_4$ in 100 mols. solution.

S.	S_1.	Sp. gr
4.2930	0 581	1 0522
3.9591	0.476	1 0431
3.2845	0.392	1.0357
2.5043	0.297	1.0271
1.6131	0.189	1.0173
0 8327	0 097	1.0089

(Charpy, A. ch. (6) 29, 26.)

Solubility in 100 pts. H_2O at t°, using $NiSO_4 + 7H_2O$.

t°	Pts. $NiSO_4$	t°	Pts. $NiSO_4$	t°	Pts. $NiSO_4$
0	29.3	37	47.5	74	68.2
1	29.7	38	48.0	75	68.8
2	30.1	39	48.5	76	69.3
3	30.5	40	49.0	77	69.9
4	31.0	41	49.6	78	70.5
5	31.5	42	50.1	79	71.1
6	32.0	43	50.6	80	71.7
7	32.5	44	51.2	81	72.3
8	33.0	45	51.7	82	72.9
9	33.5	46	52.3	83	73.5
10	34.0	47	52.8	84	74.1
11	34.5	48	53.4	85	74.6
12	35.0	49	53.9	86	75.2
13	35.5	50	54.5	87	75.8
14	36.0	51	55.0	88	76.4
15	36.5	52	55.6	89	77.0
16	37.0	53	56.1	90	77.6
17	37.5	54	56.7	91	78.2
18	38.0	55	57.3	92	78.8
19	38.5	56	57.9	93	79.4
20	39.0	57	58.4	94	80.1
21	39.5	58	59.0	95	80.7
22	40.0	59	59.6	96	81.3
23	40.5	60	60.2	97	81.9
24	41.0	61	60.7	98	82.5
25	41.5	62	61.3	99	83.1
26	42.0	63	61.9	100	83.7
27	42.5	64	62.4	101	84.3
28	43.0	65	63.0	102	84.9
29	43.5	66	63.6	103	85.6
30	44.0	67	64.1	104	86.2
31	44.5	68	64.7	105	86.8
32	45.0	69	65.3	106	87.5
33	45.5	70	65.9	107	88.1
34	46.0	71	66.5	108	88.7
35	46.5	72	67.0	108.4	88.7
36	47.0	73	67.6		

(Mulder, calculated from his own and Tobler's determinations, Scheik, Verhandel, 1864, 70.)

Solubility of Nickel Sulphate, $NiSO_4$.

(Steele and Johnson—J. Ch. Soc, 85, 116, '04; see also Etard and Mulder.)

t°	Grams $NiSO_4$ per 100 gms.		Solid Phase
	Solution	Water	
5	20.47	25.74	$NiSO_4.7H_2O$
0	21.40	27.22	"
9	23.99	31.55	"
22.6	27.48	37.90	"
30	29.99	42.46	"
32.3	30.57	44.02	"
33	31.38	45.74	"
34	31.20	45.5	"
32.3	30.35	43.57	$NiSO_4.6H_2O$
33.0	30.25	43.35	" (blue)
34.0	30.49	43.83	"
33.0	30.25	43.35	"
35.6	30.45	43.79	" (blue)
44.7	32.45	48.05	"
50.0	33.39	50.15	"
53.0	34.38	52.34	"
54.5	34.43	52.50	$NiSO_4.6H_2O$
57.0	34.81	53.40	" (green)
60	35.43	54.80	"
70	37.29	59.44	"
80	38.71	63.17	"
99	43.42	76.71	"

Transition points, hepta hydrate $\rightleftharpoons$ hexa hydrate = 31.5°.

Hexa hydrate (blue) $\rightleftharpoons$ hexa hydrate (green) = 53.3°.

Solubility of Potassium Nickel Sulphate.

t°	Grams per 100 gms. H_2O $K_2Ni(SO_4)_2.6H_2O$
0	6
10	9
20	14
25	16
30	18
40	23
50	28
60	35
70	43

[*Tables, Factors and Calculations.*]

Ammonium Nickel Sulphate $(NH_4)_2Ni(SO_4)_2.6H_2O$; Solubility in Water

(Average curve from Tobler, Locke, at 25°.)

—	G. $(NH_4)_2Ni(SO_4)_2$ per 100 gms.		—	G. $(NH_4)_2Ni(SO_4)_2$ per 100 gms.	
t°	Water.	Solution.	t°	Water.	Solution.
0	1.0	0.99	40	12.0	10.72
10	4.0	3.85	50	14.5	12.96
20	6.5	6.10	60	17.0	14.53
25	7.57	7.04	70	20.0	16.66
30	9.0	8.45			

Nickel Chloride, $NiCl_2$; Solubility in Water

(Etard; at 12°, Ditte—Compt. rend. 92, 242, '81.)

t°	Gms $NiCl_2$ per 100 gms. solution	t°	Gms. $NiCl_2$ per 100 gms. solution	t°	Gms. $NiCl_2$ per 100 gms. solution
—17	29.7	25	40.0	60	45.1
0	35.0	30	40.8	70	46.0
+10	37.3	40	42.3	78	46.6
20	39.1	50	43.9	100	46.7

1,000 cc. saturated HCl solution dissolve 4.0 grams $NiCl_2$ at 12°.

100 grams absolute alcohol dissolve 10 05 grams $NiCl_2$ at room temperature (Bodtker—Z. physik, Chem. 22, 511, '97).

Solubility of Nickel Nitrate, $Ni(NO_3)_2$, in Water

(Funk—Wiss Abh. p. t. Reichsanstalt, 3, 439, '00)

t°	Gms. $Ni(NO_3)_2$ per 100 gms. solution	Mols. $Ni(NO_3)_2$ per 100 mols. H_2O	Solid Phase
—23	39.02	6.31	$Ni(NO_3)_2.9H_2O$
—21	39.48	6.43	" "
—10.5	44.13	7.79	" "
—21	39.94	6.55	$Ni(NO_3)_2.6H_2O$
—12.5	41.59	7.01	" "
—10	42.11	7.16	" "
— 6	43.00	7.44	" "
0	44.32	7.86	" "
+18	48.59	9.3	" "
20	49.06	9.49	" "
41	55.22	12.1	" "
56.7	62.76	16.7	" "
58	61.61	15.9	$Ni(NO_3)_3.3H_2O$
60	61.99	16.0	" "
64	62.76	16.6	" "
70	63.95	17.6	" "
90	70.16	23.1	" "
95	77.12	33.3	" "

(6) WEIGHTS, ETC., OF GASES

	A	B	C	D	E	F
Gas	At 0°C and 760 m.m. dry			Sp. gr.	Net B.T.V. per cubic ft. at 60° F. and 30″ Hg.	
	Weight		Volume			
Name and Formula	Per litre	Per c. foot	Of 1 lb.	Air as unity	Dry	Moist
	Grams	lbs.	c. ft.			
Air (a)	1.2927	.0807	12.39	1.000	....	....
Hydrogen (b)	0.0899	.00561	178.25	0.0695	289	269
Oxygen	1.427	.0891	11.22	1.105	....	....
Nitrogen	1.250	.0780	12.80	0.967	....	....
Carbon Monoxide	1.249	.0780	12.82	0.966	341	318
Carbon Dioxide	1.962	.1225	8.16	1.318	....	....
Sulphur Dioxide	2.927	.179	5.89	2.21	....	890
			(@ 15° C)			
Methane	0.715	.0446	22.42	0.553	954	890
Acetylene	1.162	.0725	13.79	0.899	1,498	1,397
Coal Gas	0.50	.031	32	0.39	510–730	480–620
Mond Gas	1.06	.065	15	0.82	170	160
Water Gas	0.70	.044	23	0.54	320	300
Natural Gas	0.65	.040	25	0.50	830	770

NOTES.—(a) and (b) are the figures from which the others have been calculated as far as possible. Column A. is obtained from (b) and the international atomic weights 1916. Actual experimental values vary somewhat from these and differ according to various observers. Thus, in the case of CO_2 (gms. per litre), one authority gives 1.9652 and another 1.9768.

Column B. = Column A. x 0.06242.

" C. $= \frac{1}{B}$

" D. = Wts. in A. divided by (a).

The figures for Coal, Mond, Water, Producer and Natural Gas are approximate only. All others are the theoretical figures.

Name.	Formula.	Molecular Weight.	Sp. gr. air as unity.
Air	....	....	1.0000
Nitrogen	N_2	28.02	0.9701
Oxygen	O_2	32.00	1.1055
Sulphur dioxide	SO_2	64.06	2.2131
Chlorine	Cl_2	70.92	2.489
Hydrogen	H_2	2.016	0.0695
Carbon dioxide	CO_2	44.00	1.5201
Carbon monoxide	CO	28.00	0.9673
Hydrochloric acid	HCl	36.468	1.2595
Hydrogen sulphide	H_2S	34.086	1.1773
Nitric oxide	NO	30.01	1.0378

NOTE.—The weight of any other gas can be obtained in the case of elements, by multipling the atomic weight by 0.0695, or, in the case of compounds, by multiplying half the molecular weight by the same factor.

As 1,000 cubic feet of air weighs 80.7 lbs., the weight of the same volume of any other gas can be found by multiplying its specific gravity by that figure.

[*Tables, Factors and Calculations.*]

At about 15°C. and at atmospheric pressure:—

1,000 cubic ft of air	weighs	80.7 lbs.	
" " " " hydrogen	"	5.6 "	
" " " " oxygen	"	89.1 "	
" " " " steam	"	50.5 "	
" " " " carbonic acid gas	"	122.5 "	
" " " " sulphur dioxide gas	"	179 "	
" " " " coal gas	"	31 "	(about)
" " " " natural gas	"	40 "	"
" " " " water gas	"	44 "	"
" " " " Mond gas	"	66 "	"
" " " " Producer gas	"	67 "	"
" " " " water (liquid)	"	6,229 "	*i.e.*, over 770 times the weight of air.

8.94 lbs. water produces 178.25 cubic feet of hydrogen when electrolyzed, *i.e.*, 9 lbs. water produces about 180 cubic ft. of hydrogen and about 90 cubic ft. of oxygen by electrolysis; or 1 lb. water produces 20 cubic ft. of hydrogen and 10 cubic ft. of oxygen.

The electrolysis of 1 lb of salt would yield:—

0.017 lbs or 3.03 cubic feet of H.
0.68 lbs. of NaOH or 0.53 lbs. of Na_2O.
0.61 lbs or 3.03 cu. ft. of Cl.
1.65 lbs. of bleaching powder containing 37 per cent. Cl.

(7) WEIGHT, SOLUBILITY, ETC., OF SULPHUROUS ACID GAS (SO_2)

SO_2 is 2.21 times as heavy as air.
1 cubic ft. SO_2 at 0°C. weighs 0.179 lbs.
1 litre " " " 2.927 grams.
1 lb. SO_2 occupies 5.89 cubic ft. at 15°C.

at	20°C.	water dissolves	8.6	per cent. SO_2 by weight
"	30	" "	7.4	" " " " "
"	40	" "	6.1	" " " " "
"	50	" "	4.9	" " " " "
"	60	" "	3.7	" " " " "
"	100	" "	0.1	" " " " "

at 20°C. 1 vol. water dissolves about 39.37 vols. SO_2.
" 0°C. " " " 79.8 " "

SO_2 liquifies at 10°C. (50°F.) under ordinary atmospheric pressure or at 15°C. (59°F.) at a pressure of under 2½ atmospheres.

1 gram of lime (CaO) neutralizes 1.143 grms. SO_2 and produces 2.143 grms. $CaSO_3$.
1 gram of magnesia (MgO) neutralizes 1,600 grms SO_2 and produces 2.600 grms. $MgSO_3$.

(8) TABLE FOR CONVERTING VALUES IN PENCE OR CENTS PER "UNIT," TO PRICE IN £ STERLING PER TON, AT VARIOUS PERCENTAGES.

(Reprinted from "The Mining Magazine," London, September, 1916.)

Multiplying any figure in the 10% column by 10 will give the value of one ton of material, at 100% purity and dividing by 10, at 1% any value can be calculated from the table. Thus the value at 10c. per unit for ore containing 21.1% metal is found by adding together 0.41098, 0.020549, and 0.0020549. The values per ton calculate out the same for both the long ton, 2240 lb., and the short ton, 2000 lb., because the "unit" is 20 lb. for the former and 22.4 lb. for the latter; but it is, of course, necessary to specify which ton is used.

Quotations on ores and minerals must necessarily take account of the proportion as well as the amount of valuable metal in the material sold. Clearly an ore containing 10% of a metal is worth less *per unit* than one containing 20%. It is customary, therefore, to specify a certain standard of purity, or percentage of metal and to increase or decrease the price according to the quality of the ore above or below that standard. These standards vary with the material and often with the locality. Thus, an ore may be quoted on a "50% basis," which means that each ton delivered must contain 50% metal, or, to use the trade term, 50 "units," subject to agreed or customary penalties and premiums for variation below or above. In America, Joplin zinc ores, being very pure, are quoted on a 60% basis, meaning a content of 60% or 60 units of metallic zinc. Colorado ores, and mixed zinc ores in general, are sold on a 40% or 40 unit basis.

Price per "unit" (*i.e.* for each 1%)		PRICE PER TON OF MATERIAL AT VARIOUS PERCENTAGES OF CONSTITUENT PAID FOR.								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
Pence	Cents	£	£	£	£	£	£	£	£	£
0.12329	¼	0.0051372	0.010274	0.015412	0.020549	0.025686	0.030823	0.035960	0.041098	0.046235
⅛	0.25346	0.0052083	0.010667	0.015625	0.020833	0.026042	0.031251	0.036458	0.041667	0.046375
0.24658	½	0.010274	0.020549	0 030822	0.041098	0.051371	0.061646	0.071920	0.082196	0.092467
¼	0.50692	0.010417	0.020833	0.031251	0.041667	0.052085	0.062500	0.072919	0.083333	0.093753
0.36987	¾	0.015412	0.030822	0.046236	0.061646	0.077055	0.092467	0.10788	0.12329	0.13870
0.49317	1	0.020549	0 041098	0.061646	0.082196	0.10274	0.12329	0.14384	0.16439	0.18494
½	1.0138	0.020833	0 041667	0.062500	0 083333	0.10417	0.12500	0.14584	0.16667	0 18751
¾	1.5208	0.031251	0.062500	0.093753	0.12500	0.15625	0.18751	0.21876	0.25000	0.28126
0.98634	2	0.041098	0.082196	0.12329	0.16439	0.20549	0.24659	0.28768	0.32878	0.36988
1	2.0277	0.041667	0.083333	0.12500	0 16667	0.20833	0.25000	0.29167	0.33333	0.37500
1.4795	3	0.061646	0.12329	0.18494	0.24659	0.30822	0.36988	0.43152	0.49317	0.55481
1.9727	4	0.082196	0.16439	0.24659	0.32878	0.41098	0.49317	0.57537	0.65756	0.73975
2	4 0554	0.083333	0.16667	0.25000	0.33333	0 41667	0.50000	0 58334	0.66667	0.75000
2.4658	5	0.10274	0.20549	0.30822	0.41098	0.51371	0.61646	0.71920	0.82196	0.92467
2.9590	6	0.12329	0.24659	0.36988	0 49317	0.61646	0 73975	0.86304	0.98635	1.1096
3	6.0831	0.12500	0.25000	0.37500	0 50000	0 62500	0.75000	0.87500	1	1 1250
3.4522	7	0.14384	0.28768	0.43152	0.57537	0.71920	0.86304	1.0069	1.1507	1.2946
3.9454	8	0.16439	0.32878	0.49317	0.65756	0 82196	0.98635	1.1507	1.3151	1.4795
4	8.1108	0.16667	0.33333	0.50000	0.66667	0.83333	1	1.1667	1 3333	1 5000
4.4385	9	0.18494	0.36988	0.55481	0.73975	0.92467	1.1096	1.2946	1.4795	1.6644
4.9317	10	0.20549	0 41098	0.61646	0.82196	1.0274	1.2329	1.4384	1.6439	1.8494

5	10.138	0.20833	0.41667	0.62500	0.83333	1.0417	1.2500	1.4584	1.6667	1.8751
6	12.166	0.25000	0.50000	0.75000	1	1.2500	1.5000	1.7500	2	2.2500
7	14.194	0.29167	0.58334	0.87501	1.1667	1.4584	1.7500	2.0417	2 3333	2.6250
8	16.222	0.33333	0.66667	1.	1.3333	1.6667	2	2.3333	2.6667	3
9	18.249	0.37500	0.75001	1.1250	1.5000	1.8750	2.2500	2.6250	3	3.3750
9.8634	20	0.41098	0.82196	1.2329	1.6439	2.0549	2.4659	2.8768	3.2878	3.6988
10	20.277	0.41667	0.83333	1.2500	1.6667	2.0833	2.5000	2.9167	3.3333	3.7500
11	22.305	0.45834	0.91668	1.3750	1.8334	2.2917	2.7500	3.2084	3 6667	4.1251
Shillings	Dollars									
1	0.24333	0.50000	1	1.5000	2	2.5000	3	3.5000	4	4.5000
1.2329	0.3	0.61646	1.2329	1.8494	2.4659	3.0822	3 6988	4.3152	4.9317	5.5481
1 6439	0.4	0.82196	1.6439	2.4659	3.2878	4.1098	4.9317	5.7537	6.5756	7.3975
2	0.48667	1	2	3	4	5	6	7	8	9
2 0549	0.5	1.0274	2.0549	3.0822	4.1098	5.1371	6.1646	7.1920	8.2196	9 2467
2.4658	0.6	1.2329	2.4659	3.6988	4.9317	6.1646	7.3975	8.6304	9.8635	11.096
2 8768	0.7	1.4384	2.8768	4.3152	5.7537	7.1920	8.6304	10.069	11.507	12.946
3	0.73000	1.5000	3	4.5000	6	7.5000	9	10.500	12	13.500
3.2878	0.8	1.8439	3.2878	4.9317	6.5756	8.2196	9.8635	11.507	13.151	14.795
3.6988	0 9	1.8494	3.6988	5.5481	7.3975	9.2467	11.096	12.946	14.795	16.644
4	0.97334	2	4	6	8	10	12	14	16	18
4 1098	1	2.0549	4.1098	6.1646	8.2196	10.274	12.329	14.384	16.439	18.494
5	1.2167	2.5000	5	7.5000	10	12.500	15	17.500	20	22.500
6	1.4600	3	6	9	12	15	18	21	24	27
7	1.7034	3.5000	7	10.500	14	17.500	21	24.500	28	31.500
8	1 9467	4	8	12	16	20	24	28	32	36
8.2196	2	4.1098	8.2196	12.329	16.439	20.549	24.659	28.768	32.878	36.988
9	2.1900	4.5000	9	13.500	18	22.500	27	31.500	36	40.500
10	2.4334	5	10	15	20	25	30	35	40	45
11	2.6767	5.5000	11	16 500	22	27.500	33	38.500	44	49.500
12	2.9200	6	12	18	24	30	36	42	48	54
12.329	3	6.1646	12.329	18.494	24.659	30.823	36.988	43.152	49.317	55.481
13	3.1633	6.5000	13	19.500	26	32.500	39	45.500	52	58.500
14	3.4067	7	14	21	28	35	42	49	56	63
15	3.6500	7.5000	15	22.500	30	37.500	45	52 500	60	67.500
16	3.8933	8	16	24	32	40	48	56	64	72
16.439	4	8.2196	16.439	24.659	32.878	41.098	49.317	57.536	65.756	73 976
17	4 41366	8.5000	17	25.500	34	42.500	51	59.500	68	76.500
18	4.3800	9	18	27	36	45	52	63	72	81
19	4.6233	9.5000	19	28.500	38	47.500	57	66.500	76	85.500
20	4 8667	10	20	30	40	50	60	70	80	90
20.549	5	10.274	20.549	30.823	41.098	51.372	61.646	71.922	82.196	92.471

[Tables, Factors and Calculations.]

(9) TABLE FOR CONVERTING CENTS OR PENCE PER POUND INTO £ STERLING PER TON

(Reprinted from "The Mining Magazine," London, September, 1916.)

1 cent equals 0.49317 pence
1 penny " 2.0277 cents

1 cent equals 0 0020549 £ sterling
£1 sterling equals 486.67 cts. or 4 8667 dollars

To convert cents per pound into dollars per ton of 2000. lbs., multiply by 20.

Per pound		Per ton of	
		2000 lb.	2240 lb.
Cents	Pence	£	£
0 21725	0.10714	0.82986	1
0.24333	0.12000	1	1.1200
¼	0.12329	1.0274	1.1507
0.43450	0.21428	1.7857	2
0.48667	0.24000	2	2.2400
½	0 24658	2.0549	2.3014
0 50692	¼	2.0833	2.3333
0.65175	0 32142	2.6786	3
0.73000	0.36000	3	3.3600
¾	0.36987	3.0824	3.4521
0.86900	0 42857	3.5714	4
0 97334	0.48000	4	4.4800
1	0.49317	4.1098	4.6029
1.0138	½	4.1667	4.6667
1.0862	0.53570	4.4643	5
1.2167	0 60000	5	5.6000
1.3035	0.64286	5.3571	6
1.4600	0.72000	6	6.7200
1.5202	¾	6.2500	7
1.7034	0.84000	7	7.8400
1.7380	0.85712	7.1428	8
1.9467	0.96000	8	8.9600
1.9553	0 96428	8.0357	9
2	0.98634	8.2196	9.2058
2.0277	1	8.3333	9.3333
2.1725	1.0714	8.9286	10
2.1900	1.0800	9	10.980
2.4334	1.2000	10	11 200
3	1.4795	12.329	13.808
4	1.9727	16.439	18.412
4.0554	2	16.667	18.667
4.3450	2.1428	17.857	20
4.8667	2.4000	20	22.400
5	2.4658	20.549	23.014
6	2.9590	24.659	27.617
6.0835	3	25	28
6.5175	3.2143	25.786	30
7	3.4522	28.769	32.220
7.3000	3.6000	30	33.600
8	3.9454	32.878	36.823
8.1108	4	33.333	37.333
8.6900	4.2857	35.714	40
9	4.4385	36.988	41.426
9.7336	4.8000	40	44.800
10	4.9317	41.098	46 039
10.138	5	41.667	46.667
10.862	5.5370	44.643	50
12.167	6	50	56
13.035	6.4284	53.572	60
14.194	7	58.333	65.333
14.600	7.2000	60	67.200
15.208	7.4998	62.500	70
16 222	8	66.667	74.667
17.034	8.4000	70	78.400

Per pound		Per ton of	
		2000 lb.	2240 lb.
Cents	Pence	£	£
17.380	8.5712	71.429	80
18.249	9	75	84
19.467	9.6000	80	89.600
19.552	9.6426	80.357	90
20	9.8634	88.196	92.058
20.277	10	83.333	93.333
21.725	10.714	89.286	100
21.900	10.800	90	100 80
22.305	11	91.667	102.67
Dollars	Shillings		
0 24334	1	100	112
0.3	1.2329	123.29	138.08
0.4	1.6439	164.39	184.12
0.43450	1.7857	178.57	200
0 48668	2	200	224
0.5	2.0549	205.49	230 14
0.6	2.4658	246.58	276.17
0 65175	2.6786	267.86	300
0.7	2.8768	287.68	322.20
0.73000	3	300	336
0 8	3.2878	328.78	368.23
0.86907	3.5715	357.15	400
0.9	3.6987	369.87	414.25
0 97336	4	400	448
1	4.1098	410.98	460.29
1.0862	4.4643	446.43	500
1.2167	5	500	560
1.3035	5.3572	535.72	600
1.4600	6	600	672
1.5208	6.2500	625	700
1.7034	7	700	784
1.7380	7.1429	714.29	800
1.9467	8	800	896
1.9552	8.0357	803.57	900
2	8.2196	821 96	920.57
2.1725	8.9286	892.86	1000
2.1900	9	900	1008
2.4334	10	1000	1120
2.6767	11	1100	1232
2.9200	12	1200	1344
3	12.329	1232.9	1380.9
3 1634	13	1300	1456
3.2589	13.393	1339.3	1500
3.4068	14	1400	1568
3.6500	15	1500	1680
3.8934	16	1600	1792
4	16 439	1643.9	1841.1
4.1368	17	1700	1904
4.3450	17.857	1785.7	2000
4 3800	18	1800	2016
4.6234	19	1900	2128
4.8667	20	2000	2240
5.	20.549	2054.9	2301.4

(10) FACTORS FOR CALCULATING COST OF ELECTRIC POWER

The following data and factors will be found useful in calculating out electric power costs:—

1 horse power	equals	0.746 kilowatt.
1 kilowatt	"	1.34 horsepower.
1 h.p. year or 0.746 k.w. year..	"	8766 h.p. hours (at 365¼ days per year).
1 k.w. year..................	"	8766 k.w. hours.
1 h.p. year..................	"	6539 k.w. hours.
1 cent per k.w. hour..........	"	$65.39 per h.p. year. £13 8s. 9d. per h.p. year.

(NOTE.—The metric horsepower, as used in Norway and Sweden, is equal to only 736 kilowatts.)

Metric Prefixes.

*Micro-	= 0.000001	$= 10^{-6}$	Mega-	= 1000000	$= 10^{6}$
Milli-	= 0.001	$= 10^{-3}$	Kilo-	= 1000	$= 10^{3}$
Centi-	= 0.01	$= 10^{-2}$	Hecto-	= 100	$= 10^{2}$
Deci-	= 0.1	$= 10^{-1}$	Deca-	= 10	$= 10^{1}$

*"Micro-metre" is abbreviated to "Micron" $= 10^{-6}$ metre.

The following notes regarding electric units and their relationship are mainly quoted from "The Electric Furnace in Metallurgical Works," Lyon, Keeney and Cullen, Bureau of Mines, Washington, 1914, pp. 186 and 187:—

(11) UNITS USED IN ELECTRICAL CALCULATIONS

Ampere—The unit of current strength, or rate of flow, represented by I.
Volt—The unit of electromotive force, electrical pressure, or difference of potential, represented by E.
Ohm—The unit of resistance, represented by R.
Coulomb (or ampere-second)—The unit of quantity, Q.
Ampere-hour—3,600 coulombs, Q^1.
Joule (volt-coulomb)—The unit of energy or work, W.
Watt (ampere-volt, or volt-ampere)—The unit of power, P.
Farad—The unit of capacity, represented by C.
Henry—The unit of inductance, represented by L.
If letters are used to represent the units, the relations between them may be expressed by the following formulas, in which t represents 1 second and T 1 hour.

$$I = \frac{E}{R}, \quad Q = It, \quad Q^1 = IT, \quad C = \frac{Q}{E}, \quad W = QE, \quad P = IE.$$

As these relations contain no coefficient other than unity, the letters may represent any quantities given in terms of those units. For example, if E represents the number of volts of electromotive force, and R the number of ohms of resistance in a circuit, then their ratio, $E \div R$, will give the number of amperes of current strength in that circuit.
The above six formulas can be combined by substitution or elimination, so as to give the relations between any of the quantities. The most important of these are the following.—

$$Q = \frac{E}{R}t, \quad C = \frac{I}{E}t, \quad W = IEt = \frac{E^2}{R} t = I^2 Rt = Pt$$

$$E = IR, \; R = \frac{E}{I}, \quad P = \frac{E^2}{R} = I^2 R = \frac{W}{t} = \frac{QE}{t}$$

(12) RELATIONS OF VARIOUS UNITS

1 ampere	= 1 coulomb per second.
1 volt-ampere	= 1 watt = 1 volt-coulomb per second.
1 watt	= 0.7373 foot-pound per second. 0.0009477 heat unit per second (F). 1/746 of 1 horsepower.
1 joule	= 0.7373 foot-pound. Work done by 1 watt in 1 second. 0.0009477 heat unit.
1 British thermal unit	= 1055.2 joules.
1 kilowatt, or 1,000 watts	= 1,000/746, or 1.3405 horsepower.
1 kilowatt-hour	= 1.3405 horsepower-hours = 3600 joules.
1,000 volt-ampere hours	= 2,645,200 foot-pounds.
1 British Board of Trade unit	= 3412 heat units.
1 horsepower	= 746 watts = 746 volt-amperes. 33,000 foot-pounds per minute.

The ohm, ampere and volt are defined in terms of one another as follows: Ohm, the resistance of a conductor through which a current of 1 ampere will pass when the electromotive force is 1 volt. Ampere, the quantity of current that will flow through a resistance of 1 ohm when the electromotive force is 1 volt. Volt, the electromotive force required to cause a current of 1 ampere to flow through a resistance of 1 ohm.

Equivalent values of electrical and mechanical units:—

Unit.	Equivalent value in other units.
1 kilowatt-hour.	1,000 watt hours. 1.34 horsepower-hours. 2,654,200 foot-pounds. 3,600,000 joules. 3,412 heat units 367,000 kilogram-meters. 0.235 pound of carbon oxidized with perfect efficiency. 3.53 pounds of water evaporated from and at 212°F. 22.75 pounds of water raised from 62° to 212°F.
1 horse-power-hour.	0.746 kilowatt hour. 1,980,000 foot-pounds. 2,545 heat units. 273,740 kilogram-meters. 0.175 pound of carbon oxidized with perfect efficiency. 2.64 pounds of water evaporated from and at 212°F. 17 pounds of water raised from 62° to 212°F.
1 kilowatt.	1,000 watts. 1.34 horsepower. 2,654,200 foot-pounds per hour. 44,240 foot-pounds per minute. 737.3 foot-pounds per second. 3,412 heat units per hour. 56.9 heat units per minute. 0.948 heat unit per second. 0.2275 pound of carbon oxidized per hour. 3.53 pounds of water evaporated per hour from and at 212°F.
1 horse-power.	746 watts. 0.746 kilowatt. 33,000 foot-pounds per minute. 550 foot-pounds per second. 2.545 heat units per hour. 42.4 heat units per minute. 0.707 heat unit per second. 0.175 pound of carbon oxidized per hour. 2.64 pounds of water evaporated per hour from and at 212°F.
1 joule.	1 watt second. 0.000000278 kilowatt-hour. 0.102 kilogram-meter. 0.0009477 heat unit. 0.7373 foot-pound.
1 foot-pound.	1.356 joules. 0.1383 kilogram-meter. 0.000000377 kilowatt-hour. 0.001285 heat units. 0.0000005 horsepower-hour.
1 watt.	1 joule per second. 0.00134 horsepower. 3.412 heat units per hour. 0.7373 foot-pound per second. 0.0035 pound of water evaporated per hour. 44.24 foot-pounds per minute.
1 watt per square inch.	8 19 heat units per square foot per minute. 6,371 foot-pounds per square foot per minute. 0.193 horsepower per square foot.

[*Tables, Factors and Calculations.*]

Unit.	Equivalent value in other units.
1 heat unit.	1,055 watt-seconds. 778.6 kilogram-meters. 0.000293 kilowatt-hour. 0.000393 horsepower-hour. 0.0000688 pound of carbon oxidized. 0.001036 pound of water evaporated from and at 212°F.
1 heat unit per square foot per minute.	0.122 watt per square inch. 0.1076 kilowatt per square foot. 0.0236 horsepower per square foot.
1 kilogram meter.	7.233 foot-pounds. 0.00000365 horsepower-hour. 0.00000272 kilowatt-hour. 0.0093 heat unit.

Unit	Equivalent value in other units.
1 pound of carbon oxidized with perfect efficiency	14,544 heat units. 1.11 pounds of anthracite coal oxidized. 2.5 pounds of dry wood oxidized. 21 cubic feet of illuminating gas 4.26 kilowatt-hours. 5.71 horsepower hours. 11,315,000 foot-pounds. 15 pounds of water evaporated from and at 212°F.
1 pound of water evaporated from and at 212° F.	0.283 kilowatt-hour. 0.379 horsepower-hour. 965.7 heat units. 103,900 kilogram-meters. 1,019,000 joules. 751,300 foot-pounds. 0.0664 pound of carbon oxidized.

Current Density.—This is measured in amperes per sq. decimeter (sq. decimeter = 100 sq. cm.) or amperes per sq. foot (sq. foot = 9.29 sq. dm.).

Specific Resistance (or resistivity).—This is measured in microhms (10^{-6} ohm) per centimeter cube or per inch cube; the term microhms per cubic centimeter should be avoided as the following example will show.

A cube of copper with 1 cm. side, *i e.,* a centimeter cube has a resistance of 1.7 microhms which is the specific resistance of copper, but if the same be drawn out until it is 1 metre long and 1 sq. millimeter section its resistance is 17000 microhms (.017 ohm) although it is still 1 cubic centimeter in volume.

Resistance per cm. cube = 2.54 × resistance per inch cube.

Specific resistances are sometimes measured as a ratio to that of copper, silver or mercury.

Current Efficiency.—This ignores the voltage and is the ratio of the actual yield of metal per coulomb (to the theoretical electrochemical equivalent); 1 coulomb should theoretically yield .0000104 gm. of hydrogen and other metals in proportion to their chemical equivalent. The above figure is approximate only as it depends on temperature, concentration, etc.

Electrochemical equivalents unless otherwise stated are given in gms per coulomb

Some figures are:—

	Hydrogen.	Copper —ious	Copper —ic.	Nickel —ic.
1 coulomb yields grams	.0000104	.00066	.00033	.00030
1 ampere hour yields grams	.0373	2.37	1.19	1.09
Coulombs per gram of H or per $\frac{\text{gram-atom}}{\text{valency}}$ of any element..		97,000		

Energy Efficiency.—This is the ratio of the actual electrical energy used to the energy theoretically required to produce any given amount of decomposition. It is calculated thus:—

$$\text{Energy efficiency} = \text{Current efficiency} \times \frac{\text{theoretical volts}}{\text{actual volts}}$$

The theoretical voltage is variable, depending on the temperature and concentration.

Some theoretical voltages are approximately:—

$CuSO_4$	1 22 volts
$CuCl_2$	1.35 "
$CuCl$	1.42 "
$NiSo_4$	2 09 "
$NiCl_2$	1.85 "

The voltage may be calculated as follows:—

Volts = number of calories per gram-molecule × 43 × 10^{-6} − valency.

A voltometer measures quantity of electricity (or with the aid of a watch, the average current) by weighing the deposited metal; it is therefore a coulomb-meter or coulometer and should always be referred to as such. Volta's name is now sufficiently perpetuated in the unit "volt," and the term "voltmeter" can remain for the instrument which measures pressure.

End of Appendix.

INDEX

[NOTE.—The capital letters *R* and *A* which precede the page numbers indicate the *Report* and the *Appendix* volumes respectively.]